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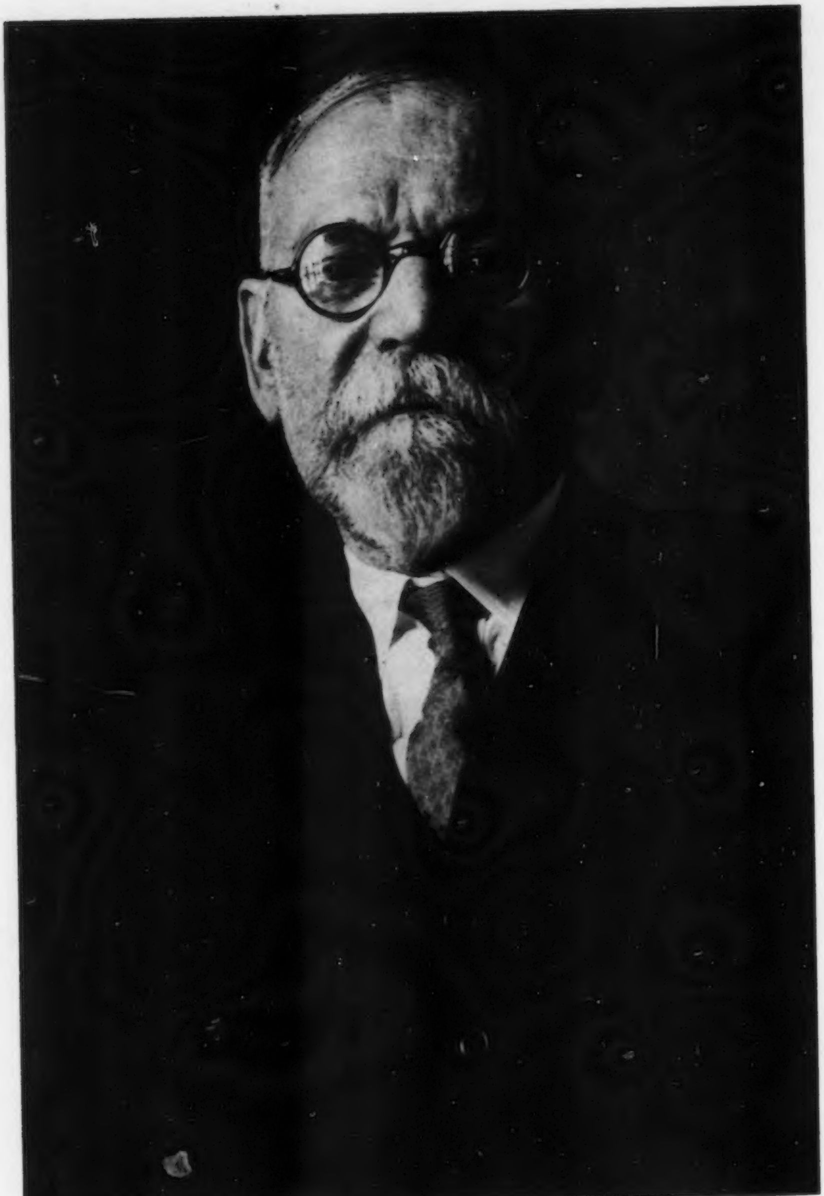

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Disharmony In Tooth Size And Its Relation To The Analysis And Treatment Of Malocclusion*

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INTRODUCTION

One of the basic fundamentals with which the orthodontist has to deal in reconstructing the denture is tooth size, specifically, the mesiodistal width of the teeth. Surprisingly few investigations have been conducted on this phase of orthodontics, as evidenced by the scarcity of literature related to the subject. The primary purpose of this study was to analyze a group of excellent occlusions and determine whether or not mathematical ratios could be set up between total lengths of dental arches, as well as between segments of dental arches. It was hoped that a method of evaluating tooth size would be found which would be an aid in diagnosis and treatment planning of orthodontic cases and also help in determining the functional and esthetic outcome of the case.

One of the first investigators to become interested in the subject of tooth size was G. V. Black[3], who in the late nineteenth century measured large numbers of human teeth. From these measurements he set up tables of mean figures which are still important references today.

More recently, quantitative studies have been made dealing with this phase of the orthodontic problem by several different investigators. Ballard[1] in 1944 studied asymmetry in tooth size; he measured the teeth on five hundred sets of casts and compared the mesiodistal diameter of each tooth with the corresponding tooth in the opposite side of the dental arch. Ninety per cent of the sample demonstrated a right-left discrepancy in mesiodistal width amounting to 0.25 millimeters or more. He advocated the judicious stripping of proximal surfaces, primarily in the anterior segments, when a lack of balance existed.

Neff[5], using two hundred cases, measured in millimeters the mesiodistal diameters of both the maxillary and the mandibular anterior teeth. He then arrived at an "anterior coefficient" by dividing the mandibular sum into the maxillary sum. The range was 1.17 to 1.41. No mean figures were given. Neff then attempted to relate the "anterior coefficient" to the degree of overbite. The overbite was determined on a percentage basis by measuring the amount of coverage of the lower central incisors by the upper incisors. End to end relation would be 0% and complete coverage 100%. By measuring normal occlusions which showed a 20% overbite, it was determined that the "anterior coefficient" for this figure was 1.20-1.22. A 20% overbite was considered to be ideal.

Ballard and Wylie[2] provided a method of computing the total mesiodistal width of the unerupted mandibular canine and premolars. This procedure was devised to be used in conjunction with Nance's[4] method of mixed dentition case analysis, in which the meas-

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urements of these three teeth, the canine and premolars, are taken from intraoral radiographs. A graph was formulated from which the mesiodistal width of the mandibular canine and premolars could be predicted after the total mesiodistal width of the mandibular incisors had been determined. It was attempted in the present investigation to compare the statistical findings of the two studies.

Wheeler[7] has published in his dental anatomy text tooth dimensions which have been devised in order that teeth may be carved and articulated in as nearly an ideal manner as possible. His figures were compared with the present study in order to see if they correlated. Figures published by The Dentists Supply Company of New York were also compared in the same manner. Their figures were based upon mathematically determined relationships and are thus a good comparative guide to evaluate how closely nature approaches a mathematical formula.

Material and Methods

The measurements used in this study were taken from fifty-five cases where excellent occlusions existed. The casts were carefully selected from a large number of excellent occlusions, most of which had been treated orthodontically (non-extraction). Of the fifty-five in the sample, forty-four were treated cases and eleven were untreated. Selections were made with extreme care, the cases being drawn from ten different private practices as well as from the Department of Orthodontics, School of Dentistry, University of Washington.

Three-inch needle-pointed dividers were used to determine the greatest mesiodistal diameter of all the teeth on each cast, excepting second and third molars. The dimensions to the nearest one-quarter millimeter were taken from a finely calibrated millimeter ruler and recorded. The following measurements were made on each set of casts:

1. The mesiodistal widths of twelve maxillary teeth, the right first permanent molar through the left first permanent molar, were totaled and compared with the sum derived by the same procedure carried out on the mandibular twelve teeth. These measurements are shown as X and X' in Figure 1. The ratio between the two is the percentage relationship of mandibular arch length to maxillary arch length which we have called the "overall ratio."

$$\frac{\text{Sum mandibular ``12''}}{\text{Sum maxillary ``12''}} \times 100 = \text{overall ratio}$$

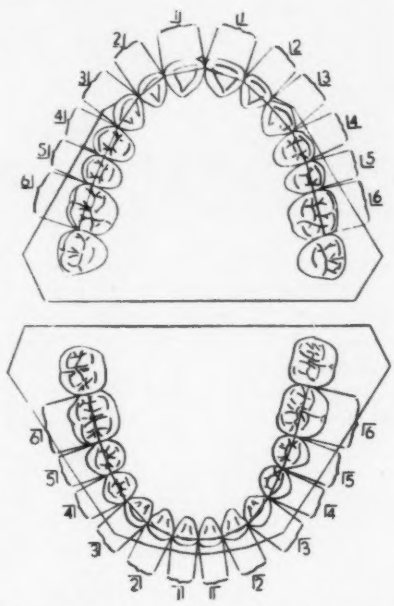

Fig. 1 X is the sum of mesiodistal diameters of max. teeth 654321 | 123456
X' is the sum of mesiodistal diameters of mand. teeth 654321 | 123456
Y is the sum of mesiodistal diameters of max. teeth 321 | 123
Y' is the sum of mesiodistal diameters of mand. teeth 321 | 123

2. The same method was used in setting up a ratio between the maxillary and the mandibular anterior teeth. Those measurements are shown as Y and Y' in Figure 1. The ratio between the two is the percentage relationship of mandibular anterior width to maxillary anterior width, and this is referred to as the "anterior ratio."

$$\frac{\text{Sum mandibular ``6''}}{\text{Sum maxillary ``6''}} \times 100 = \text{anterior ratio}$$

3. The buccal segments were divided into units in an attempt to analyze the cuspal interdigitation and possibly localize tooth size discrepancy. It is felt that the findings lack clinical significance; therefore, the buccal measurements are being omitted from this paper.

4. *The degree of overbite* was computed on a percentage basis. The amount of coverage of the mandibular central incisor by the maxillary central incisor was compared with the total length of the lower incisor. This gives an accurate picture of the overbite situation regardless of the tooth length.

5. *Overjet* was measured as the distance from the labial surface of the mandibular central incisor to the junction of the incisal and lingual surfaces of the maxillary central incisor. A finely calibrated millimeter ruler was used. The horizontal level selected for the measurements was the incisal edge of the maxillary central.

6. *The angles of the maxillary and mandibular incisors to the occlusal plane were measured.* This was determined by measuring the angles formed by the labial surfaces of the incisors with the base of the cast which was trimmed parallel to the occlusal plane.

7. *Incisor length* or the incisogingival height of the maxillary and mandibular central incisors was recorded.

8. *Cusp height* was measured with a specially designed divider which allowed measurement from the cusp tip to the depth of the central sulcus midway mesiodistally.

Statistical Analysis

The data were judged statistically and the following are the abbreviations and formulae of the statistical methods used:

S.E.M.—Standard error of the mean. This test predicts the degree of variation to be expected in the mean if the experiment were repeated on other similar samples.

S.D.—Standard deviation. This is the constant which measures in absolute terms the degree of scatter or dispersion about the mean.

C.V.—Coefficient of variation. The coefficient of variation relates the standard deviation to the mean by expressing the standard deviation as a percentage of the mean. In order for the standard deviation to be statistically significant in relation to the mean, the coefficient of variation percentage should be small.

C.C.—Coefficient of correlation. This test gives a method of correlating two measurements from the same sample.

Findings

The ratio

$$\frac{\text{Sum mandibular ``12''}}{\text{Sum Maxillary ``12''}} \times 100$$

was developed for each individual of the sample, and the following resulted:

Range	87.5-94.8
Mean	91.3
S.D.	1.91
S.E.M.	.26
C.V.	2.09%

TABLE 1

Similar data were compiled in analyzing the anterior ratio of each individual, this ratio being

$$\frac{\text{Sum mandibular ``6''}}{\text{Sum maxillary ``6''}} \times 100.$$

Range	74.5-80.4
Mean	77.2
S.D.	1.65
S.E.M.	.22
C.V.	2.14%

TABLE 2

In order to compare our data with that published by Neff, the problem was set up in reverse fashion:

$$\frac{\text{Sum maxillary ``6''}}{\text{Sum mandibular ``6''}} = \text{``anterior coefficient''}$$

	Author	*Neff*
Range	1.24-1.34	1.17-1.41
Mean	1.29	Not given, but the
S.D.	.027	ideal was deter-
S.E.M.	.0036	mined to be 1.20-
C.V.	2.09%	1.22.

TABLE 3

The coefficient of correlation between the overall ratio and the anterior ratio was +0.5, which is statistically significant.

Table 4 gives the information concerning percentage of overbite.

Range	11.8-53.9
Mean	31.3%
S.D.	10.2
S.E.M.	1.37
C.V.	32.6

TABLE 4

In order to determine if overbite is related to tooth size, a coefficient of correlation "r" was run between the anterior ratio and the per cent of overbite.

r = (Treated Cases) +.053
r = (Untreated Cases) —.094

The mean overjet was computed to be 0.74 mm.

Angles of the maxillary and the mandibular central incisor labial surfaces to the occlusal plane were taken in order to record the axial inclination of the crowns of these teeth to each other. The mean was 177 degrees.

Both the maxillary and the mandibular centrals were measured from the incisal edge to the gingival margin. A coefficient of correlation between the two measurements was calculated and found to be +0.76. Since this is a high correlation, either of the centrals may be used in calculating the coefficient of correlation between incisor length and degree of overbite. The mandibular central was selected and the coefficient of correlation was +0.39.

Cusp height is not constant throughout the denture of a given individual. The height of the cusps of the premolars was invariably greater than that of the molars. In recording the data an average between the height in the two areas was taken. The coefficient of correlation between percentage of overbite and cusp height was calculated.

Mean — 1.9 mm.
r = (Treated cases) +0.29
r = (Untreated cases) +0.28

Table 5 shows the relationships that existed between the premolars.

	Teeth Compared	Mean	r
1.	Max. First Premolar	7.04	
	Mand. First Premolar	7.15	0.96
2.	Max. Second Premolar	6.84	
	Mand. Second Premolar	7.27	0.50
3.	Max. First Premolar	7.04	
	Mand. Second Premolar	7.27	0.57
4.	Max. Second Premolar	6.84	
	Mand. First Premolar	7.15	0.61

TABLE 5

The coefficient of correlation between the sum of mesiodistal widths of the four mandibular incisors and the sum of the canine, first and second premolars arrived at by Ballard and Wylie was +0.64. The result in this study was +0.65.

Discussion

It was felt that a more satisfactory and significant discussion of the findings could be offered if the presentation were to be developed around actual cases that had been collected for the

study. Figure 2 depicts an untreated excellent occlusion. This is the dentition of a fourteen-year old girl. There were no restorations or carious lesions. Measurements and ratios recorded from this ideal occlusion were compared with means derived from the complete sample of fifty-five cases. The comparisons are summarized in Table 6.

A statistical analysis of both the overall ratio, Figure 1, measurements X and X', and the anterior ratio, Figure 1, measurement Y and Y', indicated a small degree of variation in the individual measurements about the mean. In the overall ratio (Table 1) a standard deviation of 1.91 for a mean of 91.3 ± 0.26 is very small as verified by the correspondingly small coefficient of variation, 2.09%. The same pattern held true also for the anterior ratio (Table 2). For a mean of 77.2 ± 0.22, the standard deviation of 1.65 is significantly small as again indicated by the coefficient of variation, 2.14%. Both ratios derived from the case in Figure 2 compare very favorably with the mean figures, as demonstrated in Table 6.

The anterior ratio was reversed so that it could be seen if the resultant findings were in agreement with those published by Neff (Table 3). This is not a legitimate comparison because no mean figures were published in his study; but it was stated that for a 20% overbite, the "ideal anterior coefficient" should be 1.20-1.22. Dr. Neff also makes the approximation that for a coefficient of 1.30, which most nearly corresponds to our mean of 1.29, the overbite should be 35%. The mean overbite derived for this sample was 31.3%.

The +0.5 coefficient of correlation between the anterior ratio and the overall ratio is not a particularly high one, but still it must be considered significant. This indicates that as the anterior ratio increases, the overall ratio also increases in a fairly proportionate manner.

An attempt was made to analyze the overbite problem from several different aspects. It was noted that there was a considerable range in the degree of overbite in this normal sample as demonstrated in Table 4. It then seemed desirable to relate the overbite percentage to the three following factors: the anterior ratio, the length of the central incisors, and the cusp height. In all cases the coefficients of correlation were very low; therefore, overbite did not vary at all proportionately with variations in any of the aforementioned factors.

	Untreated Excellent Occlusion	*Mean*
Overall Ratio	91.11	91.3
Anterior Ratio	77.6	77.2
Overbite	31.2	31.3
Overjet	0.5 mm.	0.74 mm.
Incisor Angle	175.5°	177°
Cusp Height	2.0 mm.	1.9 mm

TABLE 6

A comparison of an untreated excellent occlusion (Figure 2) with the mean figures derived from this study.

It has been stated, and was also suspected by the author, that a direct relationship between the anterior tooth ratio and degree of overbite would exist in any given case, i.e., as the numerical ratio increased or decreased, the degree of overbite would fluctuate in a proportionate manner. Previous findings which upheld the aforementioned theory could not be substantiated by a statistical evaluation of measurements compiled for this study, even when the untreated normals were handled as a separate group. With this group of untreated normals the problem of degree of overbite and its relations was repeated. The coefficients of correlation did not vary significantly when the two categories were compared. The sample was divided and the untreated

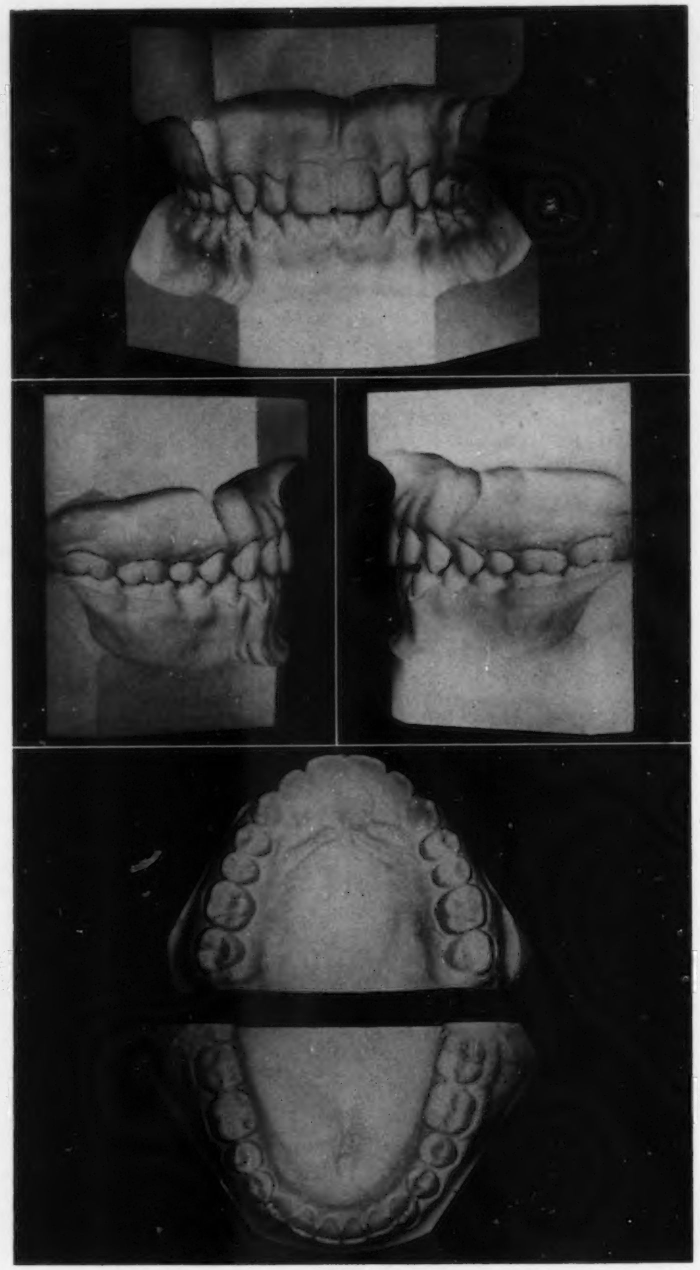

Fig. 2

component was related as a separate unit because it could be argued that the overbite which was probably altered in treatment had not in all of the cases had a chance to settle to its "normal" or state of balance with the other factors which influence occlusion. Since the coefficients were so similar, no difference was found between the two groups.

It is conceivable that the angle of the upper incisor to the lower incisor is an important factor in determining the amount of overbite in a given individual. This fact is suspected, but a satisfactory method of relating this angle to the occlusal plane could not be worked out and it remains an hypothesis. Perhaps a cephalometric study could solve this problem.

Table 5 was devised to see if any general conclusions could be drawn concerning the mean widths and variations in width of the premolars. From analyzing the figures on this chart, one could, in theory, state that from a size standpoint only, first premolars are the teeth of choice to be removed in extraction cases. Their means are the most closely related in that they are the two that most nearly correspond in mesiodistal diameter. The coefficient of correlation of $+0.96$ between mesiodistal widths of maxillary first premolars to mandibular first premolars is highly significant and indicates that if one first premolar is large, generally speaking, the other first premolar of the opposite arch will also be proportionately large. The next most desirable combination as far as mesiodistal width is concerned would be the maxillary first premolars and the mandibular second premolars. The least desirable relationship seems to go between the second premolars.

It must be emphasized again that these statements are made in theory only because the results tabulated herein were derived from the use of mean figures. Mean figures can only indicate a trend. Concrete statements concerning them should not be made, but since the coefficient of correlation test is not related to means, the high correlation between first premolar widths is very significant and cannot be disregarded. Nevertheless, one must always remember to look upon each patient as an individual and then proceed to use these findings as an aid in determining the actual condition existing.

The presentation of the two following cases which presented a marked disharmony in tooth size may help to show the clinical application of the ratios described previously.

Figure 3 depicts four views of a malocclusion in which the overall ratio and the anterior ratio were both considerably deviated from the means of this investigation. The overall ratio was 96.46 and the anterior ratio was 86.45. The fact that these figures are larger than their means indicates that the maxillary arch is too small for the existing mandibular arch. The buccal measurements were made and the resulting ratio found to be essentially one to one. From this it was suspected that the anterior segments were at fault. This suspicion was borne out by the setup in Figure 4. Interdigitation in the buccal segments was satisfactory, but in the anterior segment the best that could be achieved was an end to end relationship which, as shown in the photographs, would be very unsatisfactory.

By substituting in the anterior ratio formula,

$$\frac{\text{Sum mandibular ``6'' (X)}}{\text{Sum maxillary ``6'' (48)}} \times 100 = 77.2$$

X the unknown was found to be 37.05 mm. This is the mesiodistal dimension that the mandibular six anteriors should have ideally. Since this unit

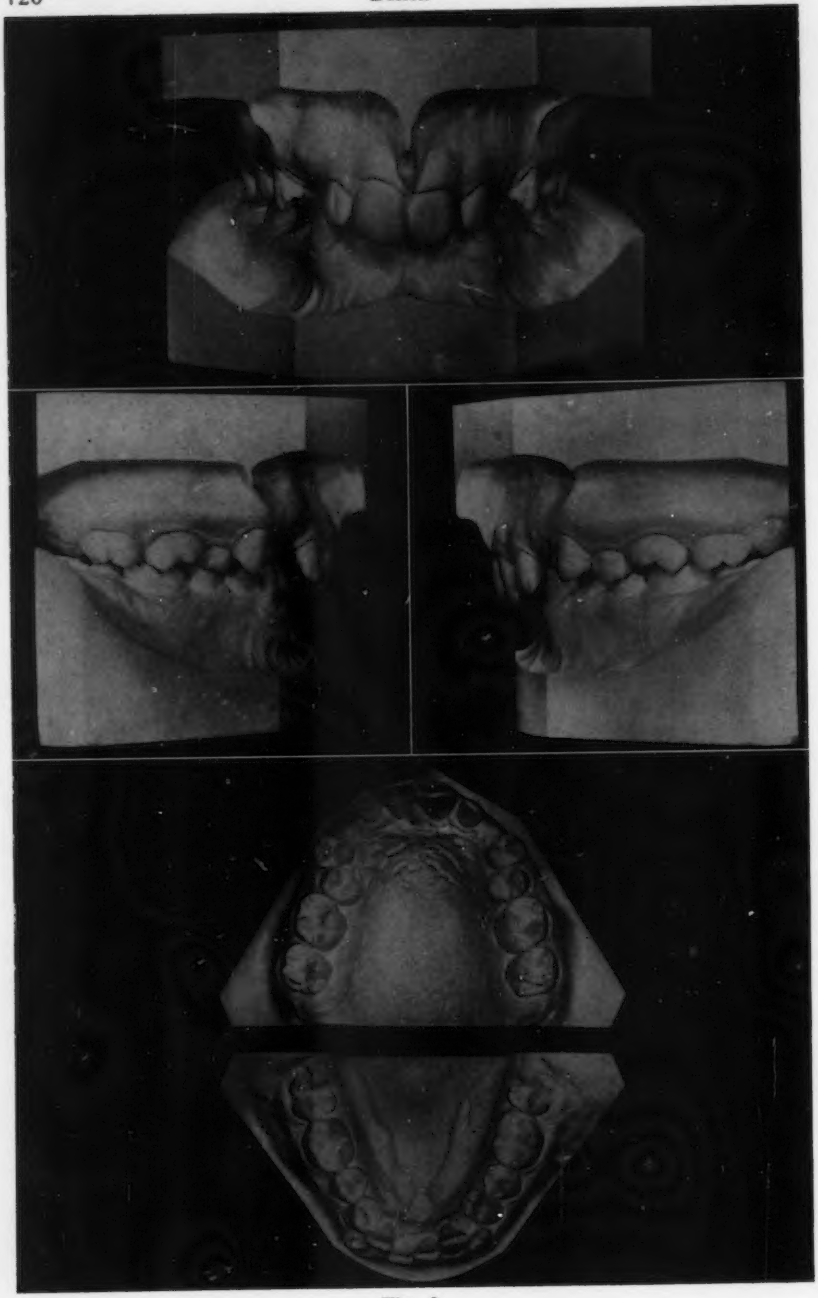

Fig. 3

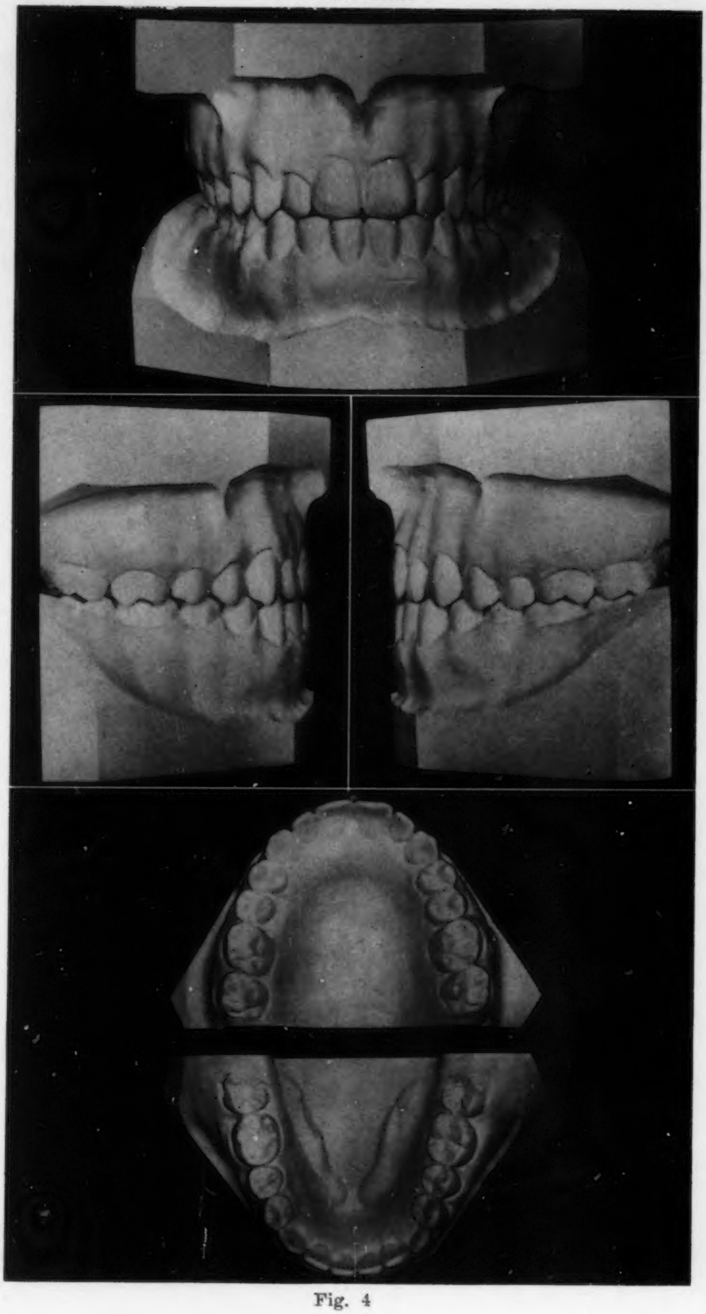

Fig. 4

actually measured 41.5 mm., it was noted that if a satisfactory anterior relationship were to be achieved, the mandibular segment should be reduced approximately 4.5 mm. By inserting this reduction in the overall formula also, the result was 92.0, within the range of normality, which indicated that the size discrepancy was confined to the anteriors.

The removal of 4.5 millimeters of tooth structure by stripping the four mandibular incisors and the mesial surface of the canines, was considered to be impractical.

The other alternative for reducing this dimension was the extraction of a central incisor whose mesiodistal width was 5.5 millimeters. The ratios were then reduced to 75.0 for the anterior and 91.03 for the overall. These readings are slightly below the mean, but the result is demonstrated by the setup in Figure 5. If the mandibular anterior segment were left intact, the final esthetic result would be far from desirable because extreme maxillary anterior spacing would be inevitable, that is, if the buccal segments were in a Class I molar relationship.

The malocclusion in Figure 6 demonstrated a somewhat different type of disharmony, being a case in which the discrepancy in size was not confined to one segment, but involved a complete dental arch. The ratio readings for this individual were 82.8 for the overall, and 70.3 for the anterior, which indicates that the maxillary arch is too large for the existing mandibular arch. The setup in Figure 7 bears this out. With the first molars placed in a Class I relationship, it is obvious that a marked discrepancy in tooth size exists between the two arches. Not only is there a marked maxillary anterior overjet, but the disharmony also extends to the buccal segments, making it impossible to obtain proper canine and premolar interdigitation.

By substituting in the overall formula,

$$\frac{\text{Sum mandibular ``12'' (87)}}{\text{Sum maxillary ``12'' (X)}} \times 100 = 91.3$$

X was found to be 95.3. This is 9.7 mm. smaller than 105 mm., the actual measurement recorded; therefore, the maxillary arch is excessive by 9.7 mm. Then by substituting in the anterior ratio,

$$\frac{\text{Sum mandibular ``6'' (36)}}{\text{Sum maxillary ``6'' (X)}} \times 100 = 77.2$$

(Mean), and solving, we find that X is 46.7 mm. By subtracting 46.7 from the 52.0 that existed, it is seen that the maxillary anterior segment is excessive by 5.3 mm. This leaves 4.4 mm. of the overall excess to be confined to the buccal regions.

A setup of this case (Figure 8) was made by removing 5 mm. of tooth structure from the maxillary anterior segment by the stripping of the following teeth: the mesial and distal surfaces of the four incisors, and the mesial surface of the canines. Extraction was considered to be necessary in the maxillary arch so second premolars were removed and the first molars were brought forward into a Class II molar relationship. This allowed satisfactory intercuspation in the buccal segments, which previously had not been possible.

Of clinical significance is the fact that the analysis can be so quickly and easily carried out. From a set of casts the various tooth measurements on each dental arch are punched along straight lines drawn upon a card. The dimensions can then be determined from the use of a finely calibrated millimeter ruler. The ratios are then set up and the results compared to the means published here. If a marked deviation occurs, a diagnostic setup can verify and give the exact picture of the conditions that exist which will affect the plan of treatment. It is felt

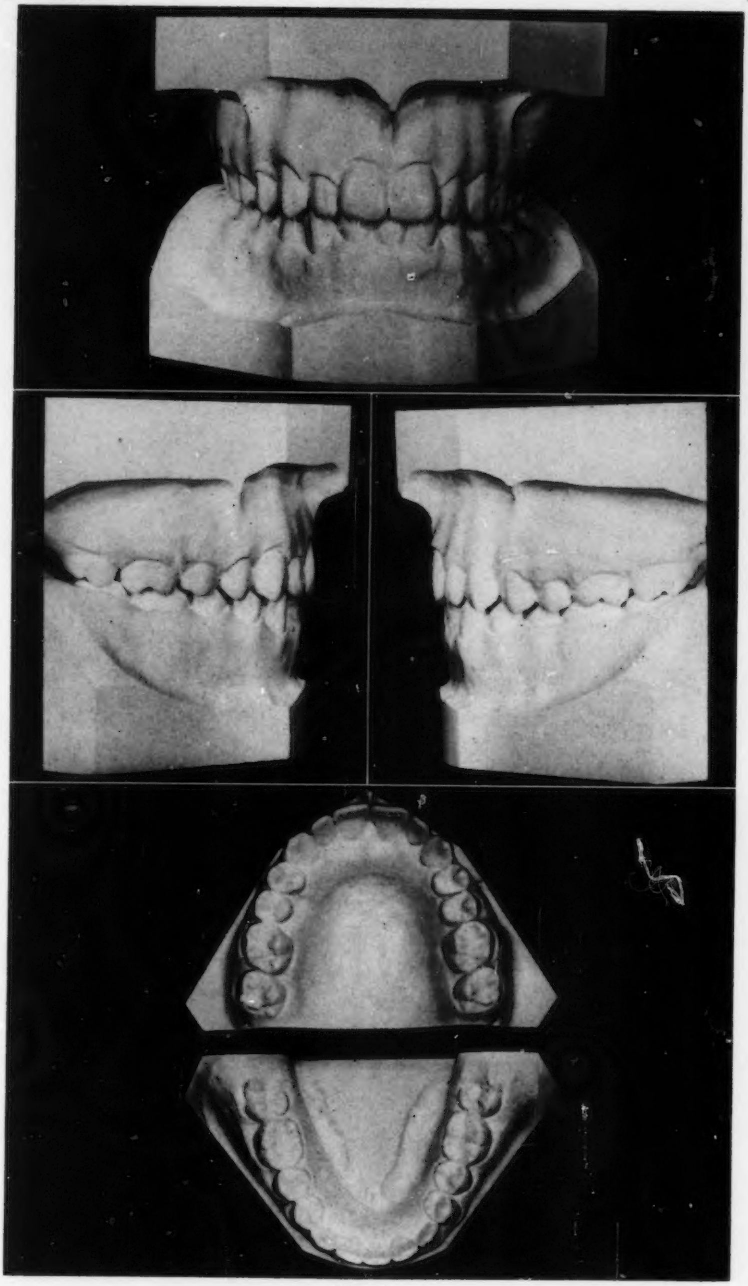

Fig. 5

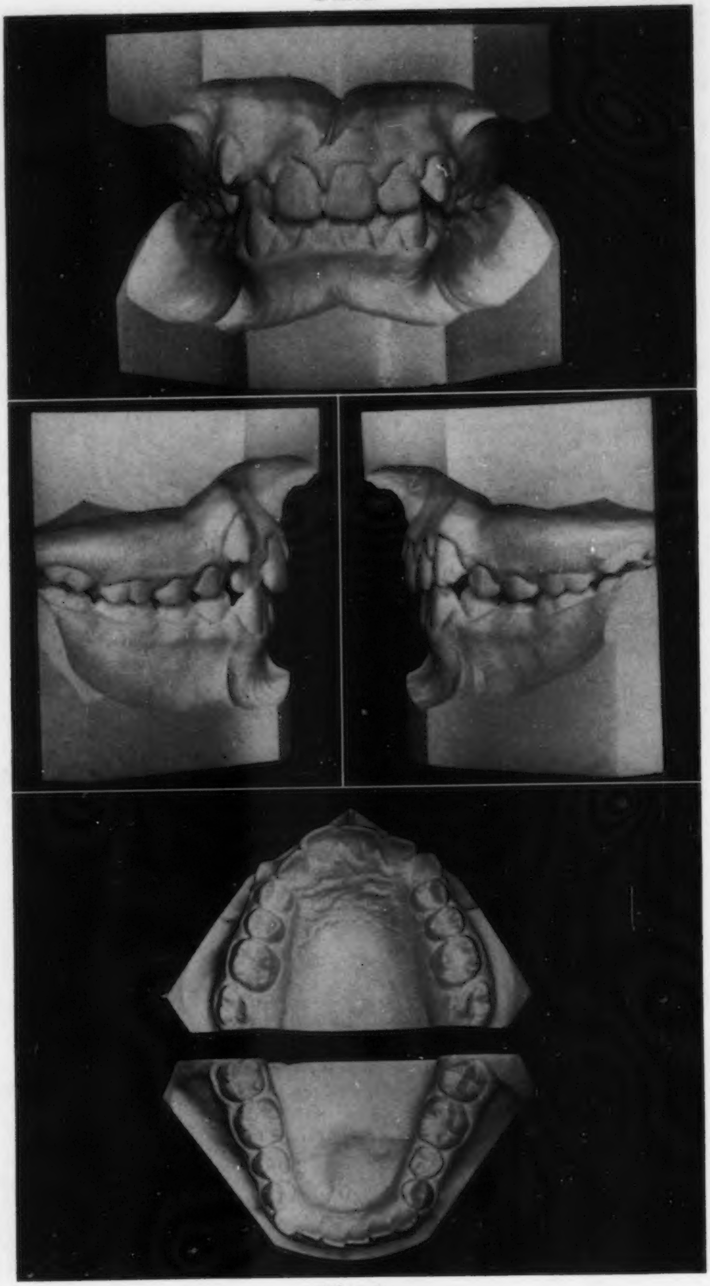

Fig. 6

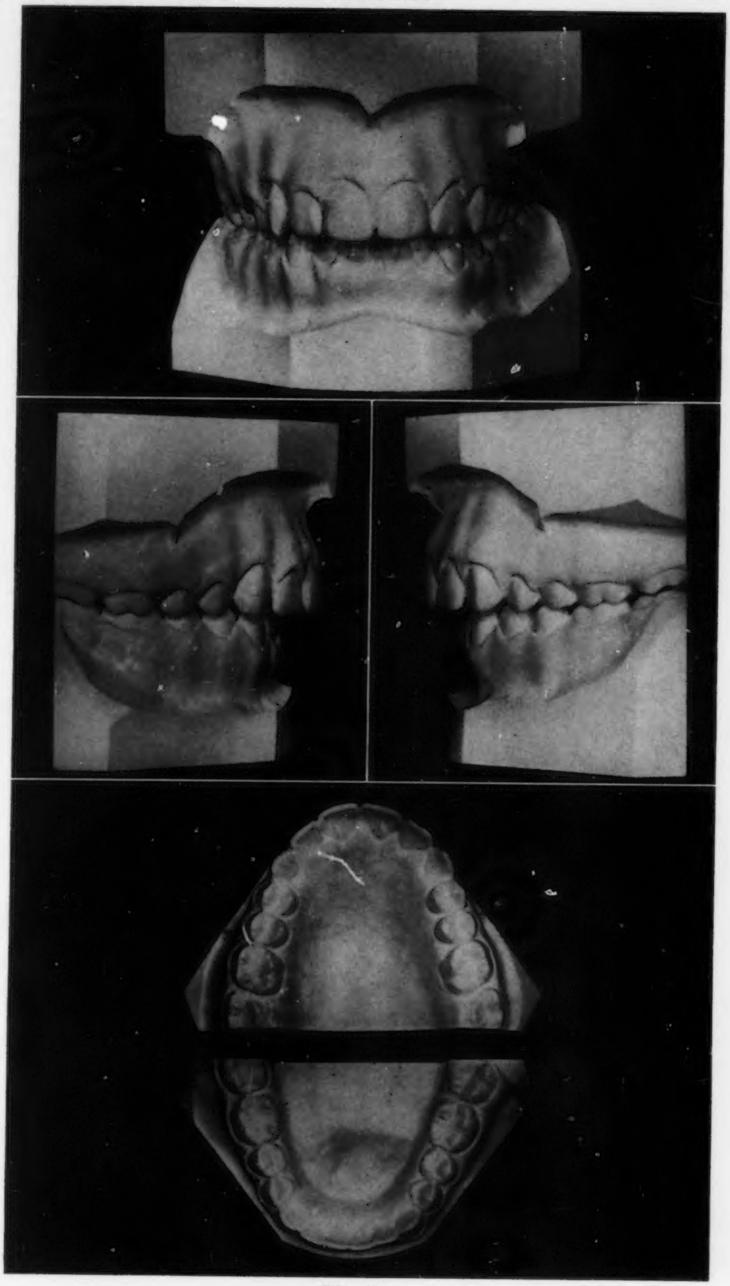

Fig. 7

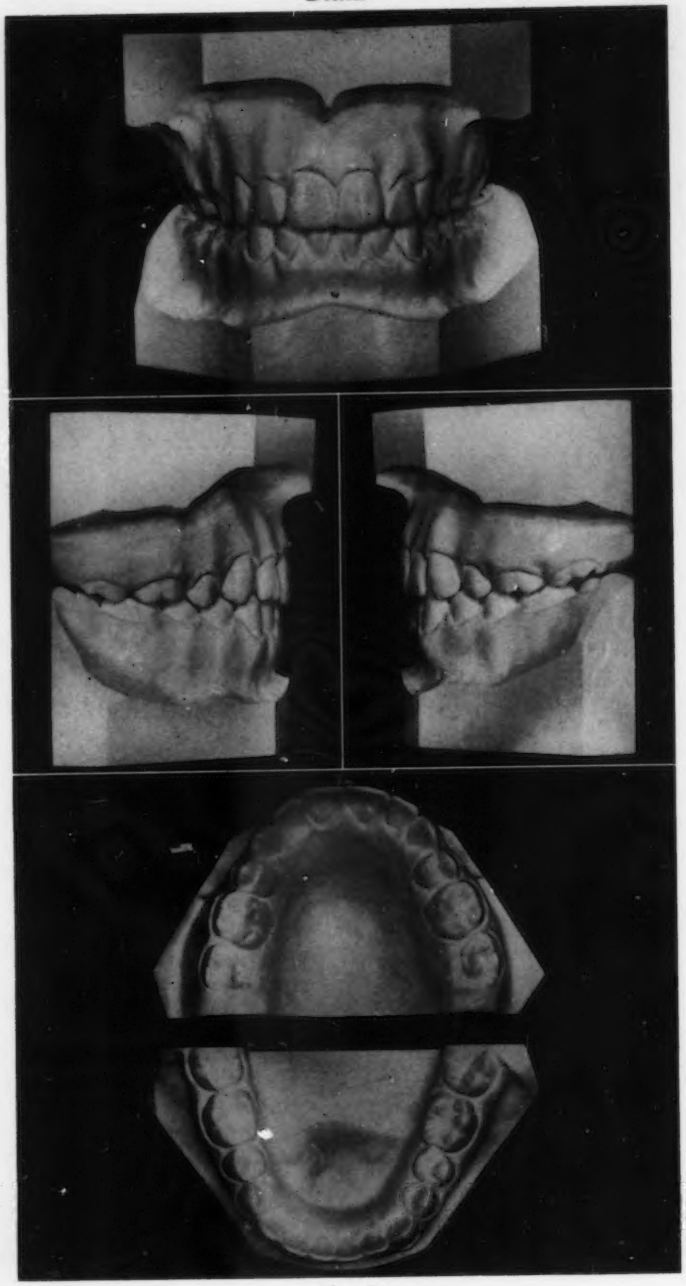

Fig. 8

Analysis of Tooth Size Discrepancies

OVERALL RATIO

Sum mandibular "12"__________mm. / Sum maxillary "12"__________mm. = ________ X 100 = __________ % Overall ratio

Mean 91.3 = 0.26
S.D. (σ) 1.91
Range 87.5 - 94.8

Max. "12"	Mand. "12"	Max. "12"	Mand. "12"	Max. "12"	Mand."12"
86	77.6	94	85.8	103	94.0
86	78.5	95	86.7	104	95.0
87	79.4	96	87.6	105	95.9
88	80.3	97	88.6	106	96.8
89	81.3	98	89.5	107	97.8
90	82.1	99	90.4	108	98.6
91	83.1	100	91.3	109	99.5
92	84.0	101	92.2	110	100.4
93	84.9	102	93.1		

PATIENT ANALYSIS

If the overall ratio exceeds 91.3 the discrepancy is in excessive mandibular arch length. In above chart locate the patient's maxillary "12" measurement and opposite it is the correct mandibular measurement. The difference between the actual and correct mandibular measurement is the amount of excessive mandibular arch length.

__________ − __________ = __________
actual mand. "12" correct mand. "12" excess mand. "12"

If overall ratio is less than 91.3:

__________ − __________ = __________
actual max. "12" correct max. "12" excess max. "12"

ANTERIOR RATIO

Sum mandibular "6"__________mm. / Sum maxillary "6"__________mm. = ________ X 100 = __________ % Anterior ratio

Mean 77.2 = 0.22
S.D. (σ) 1.65
Range 74.5 - 80.4

Max. "6"	Mand. "6"	Max. "6"	Mand. "6"	Max. "6"	Mand. "6"
40.0	30.9	45.5	35.1	50.5	39.0
40.5	31.3	46.0	35.5	51.0	39.4
41.0	31.7	46.5	35.9	51.5	39.8
41.5	32.0	47.0	36.3	52.0	40.1
42.0	32.4	47.5	36.7	52.5	40.5
42.5	32.8	48.0	37.1	53.0	40.9
43.0	33.2	48.5	37.4	53.5	41.3
43.5	33.6	49.0	37.8	54.0	41.7
44.0	34.0	49.5	38.2	54.5	42.1
44.5	34.4	50.0	38.6	55.0	42.5
45.0	34.7				

PATIENT ANALYSIS

If anterior ratio exceeds 77.2:

__________ − __________ = __________
actual mand. "6" correct mand. "6" excess mand. "6"

If anterior ratio is less than 77.2:

__________ − __________ = __________
actual max. "6" correct max. "6" excess max. "6"

Fig. 9

that the ratio results can give one an insight as to how the setup should be approached, i.e., which teeth might most logically be extracted if such procedure is deemed necessary. It must also be pointed out that the need for the extraction of a tooth or teeth is not necessarily confined to the case where shortened arch length exists. Gross disharmonies in tooth size may indicate the removal of a dental unit or units even where there is adequate arch length. Conversely, tooth size discrepancies may be corrected by the placing of overcontoured restorations where indicated.

Figure 9 portrays a simple analysis sheet drawn up for use by the orthodontic practitioner. It has also been a part of the diagnostic procedure for

every case treated in the orthodontic clinic of the University of Washington since 1953.

Mesiodistal diameter figures for all the teeth were taken from Wheeler's[6] text of dental anatomy. These dimensions were considered to be ideal for the carving and articulating of the teeth in making the perfect setup. In using his figures and computing the ratios, the results were found to be 91.4 for the overall and 77.8 for the anterior. This correlates closely with results derived from this study.

A comparison of widths of anterior segments of artificial teeth when set up (data published by the Dentists Supply Company of New York) showed that the mean of the anterior ratios for 61 moulds was 76.86.*

* These figures were based upon mathematically determined relationships.

During the search for excellent occlusions a striking example of a man-made discrepancy in tooth size was discovered. The occlusal views of the case, Figure 10 (above), demonstrate very well how the mesiodistal diameters of all the teeth comprising the maxillary buccal segments except the right first premolar have been increased by the overcontouring of restorations. Measuring casts made before and after operative dentistry and orthodontic treatment revealed that the left maxillary buccal segment (excluding second molars) had been increased in length by 2 millimeters and the right side by 1.25 millimeters. The corresponding mandibular segments had been increased in dimension also, but only a negligible amount, approximately 0.25 millimeters. Fewer restorations were present in the mandibular denture.

The effect of overcontoured restorations on occlusal relationship is best illustrated by the left lateral view shown in Figure 10 (below). The molars are in a good Class I relationship, but it is clearly demonstrated that the canine and premolar pattern of occlusion is faulty, this portion of the maxillary buccal segment being anteriorly placed in relation to the mandibular segment. This is a good illustration of how an overzealous dentist can alter tooth size to the extent that shortened arch length is the result.

Summary and Conclusions

Fifty-five excellent occlusion cases were selected and various measurements were made on the casts. These included a determination of the mesiodistal diameters of all the individual teeth, certain buccal segment measurements, as well as the degree of overbite and overjet, the angle of the maxillary central incisor to the mandibular central incisor, central incisor lengths, and cusp height. From statistical analyses of the data, the following conclusions were made:

1. The tooth size data were compared to that published by both Black and Ballard and the results of all were found to be closely related.
2. When the twelve maxillary teeth were compared with the twelve mandibular teeth in a ratio as

$$\frac{\text{Sum mandibular ``12'' x 100}}{\text{Sum maxillary ``12''}} =$$

   overall ratio, a statistically significant mean, standard deviation, and coefficient of variation were found to exist. They were 91.3 ± 0.26, 1.91, and 2.09% respectively.
3. In comparing the six maxillary anterior teeth to the six mandibular anterior teeth in a similar ratio as in 1 above,

$$\frac{\text{Sum mandibular ``6'' x 100}}{\text{Sum maxillary ``6''}} = \text{anterior ratio}$$

   equally significant findings were obtained. For a mean of 77.2 ± 0.22, the standard deviation was 1.65 with a coefficient of variation of 2.14%.

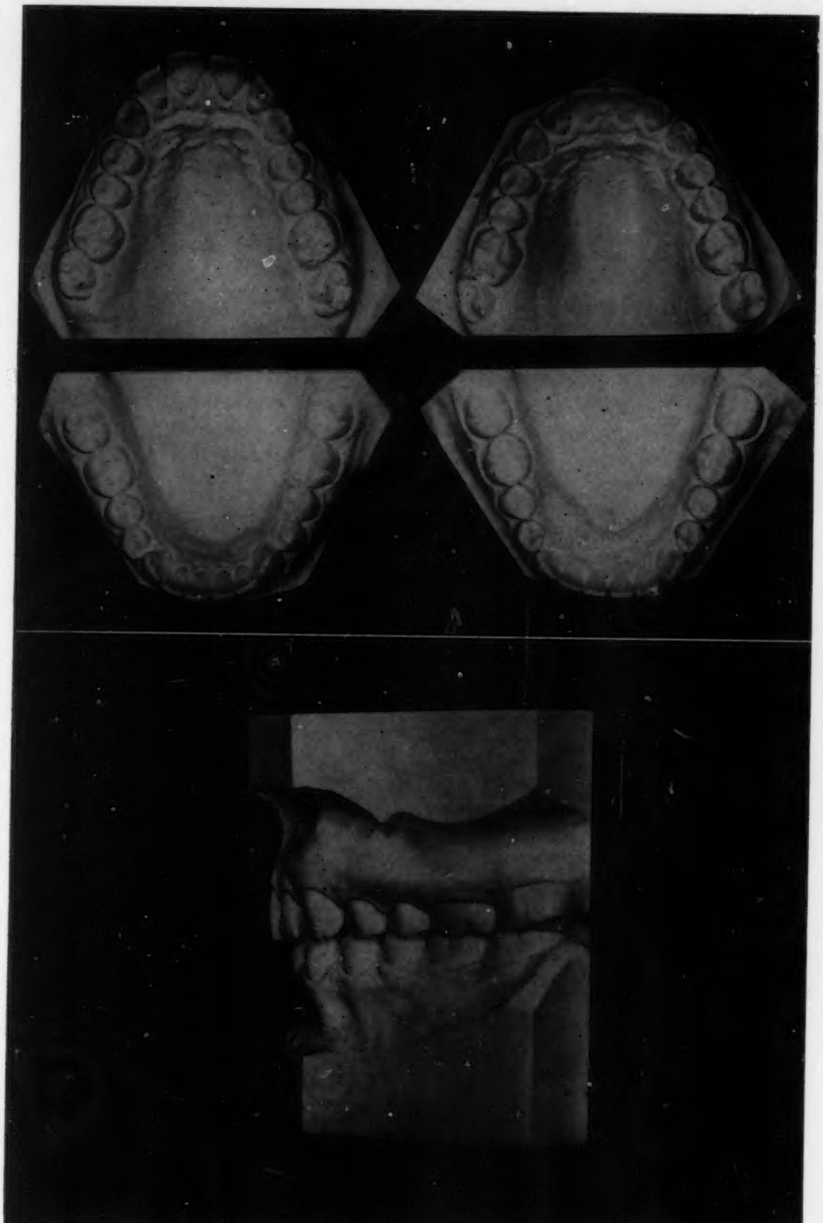

Fig. 10

4. The maxillary and mandibular buccal segments can be divided so as to give units which can be compared one with another. This procedure can be an aid in localizing tooth size disharmonies which would alter the occlusal relationships desired from orthodontic treatment.
5. The degree of overbite had a wide range of variability within this sample of excellent occlusions. The mean was 31.3% with a range of 11.8% to 53.9%. The standard deviation was 10.2 with a coefficient of variation of 32.6.
6. A significant coefficient of correlation could not be found when the degree of overbite was related to incisor length.
7. A significant coefficient of correlation could not be found when the degree of overbite was related to tooth size, via the anterior ratio.
8. Overbite was related to cusp height by the coefficient of correlation. A +0.28 indicated a very poor correlation between these two.
9. Premolar relationships were studied by analyzing the means of the mesiodistal diameters along with coefficients of correlation. The study emphasized the need for considering premolar sizes on an individual basis before the final decision is made in extraction cases.
10. A practical example of the disharmony in occlusal relationships that can be caused by increasing tooth width with over-contoured restorations has been shown.
11. The statistical evaluation given by Ballard and Wylie in the study on mixed dentition case analysis was repeated in this investigation with very similar results.
12. The clinical implication of the ratios devised has been demonstrated. It is felt that they can be one of the tools used in orthodontic diagnosis, but in the final analysis should be considered as a preliminary step to the diagnostic setup. The importance of the diagnostic setup should not be overlooked. However, the necessity for it can be determined by applying the ratios described in this study.

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Some Observations On Extraoral Treatment*

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These observations embody a recapitulation of my clinical experience with extraoral treatment and illustrations of treated malocclusions. The latter are intended to show: 1) effects, 2) limitations, and 3) the method as an auxiliary with other appliances.

Soon after the end of World War II S. J. Kloehn popularized extraoral treatment for Class II, Division 1 malocclusions. Almost ten years ago I was privileged to spend time in his office to observe its clinical application. The appliance intrigued me because of its simplicity and surprised me by the degree of tooth movement clinically observed. Many of you may have used the appliance before Kloehn, as did Angle, Case and Oppenheim. It was the latter's report, (1936), which stimulated Kloehn's interest. Numerous others have contributed material on this subject since 1950, most of them including x-ray records. Among these are Boman, Block, Blueher, Epstein, Ericsson, Graber, Ketterhagen, King, Nelson and Weinstein.

I initially assumed that extraoral force alone, or with a bite-plate, was a method capable of satisfactorily correcting many Class II, Division 1 malocclusions. This proved to be fallacious to put it mildly. It should be inserted here that my experience in treating Class II, Division 1 malocclusions during the mixed dentition has been disappointing.

Although adequate correction with extraoral therapy was sometimes gratifying, there were too many instances where I could not forecast such correction. This of course is true of any treatment method. On the one hand there were a few rapid responses but on the other there were too many which had to be completed with more conventional appliances. Such additional treatment was originally at my expense; I have learned the hard way to be more temperate.

These disappointments have had three results. First, I have become more critical in selecting patients for the extraoral appliance; secondly, the possible need for other appliance methods is invariably emphasized; thirdly, I have arbitrarily set a six month limit on the use of extraoral force to know whether it alone will be satisfactory.

Effects of Treatment

Serial roentgenographic records by others have adequately shown the effects of extraoral treatment. These may involve posterior tipping of the upper first molars, their bodily posterior movement or simply a cessation of the usual downward and forward migration accompanying developmental growth. Serial roentgenographic records made before treatment and at the end of active treatment compared with those made a significant interval subsequent to removal of all appliances are, however, seldom seen.

Superposing tracings of lateral cephalometric x-rays made prior to treatment on those at the end of treatment indicates varying degrees of tooth tipping and, if a biteplate has been used, remarkable elongation of the first molars. The tipping may be seen in all the maxillary teeth, including the third molars if present, and it may affect the nasal plane, ANS-PNS. The posterior

*Read before the January 27, 1958 meeting of the Cleveland Society of Orthodontists.

tooth tipping combines with the biteplate to force a downward and backward rotation of the mandible thus reducing the overbite anteriorly. My records subsequent to removal of all mechanical support show a pronounced tendency of all structures, particularly the teeth, to recover from the effects of treatment.

This tipping has been denied by some and criticized indignantly by others. While it can be minimized by manipulation of the appliance, I have not attempted to prevent it, having seen too many satisfactory clinical results with other appliances where such tipping was encouraged.

My records show only minor permanent alteration of the hard and soft tissues. This contrasts with the assertions of some as to the "dramatic" changes gained.

I can not refrain at this point from speculating on the possible growth stimulus of orthodontic treatment. In most instances, as you may see for yourselves, while the extraoral force is tipping maxillary teeth down and back, there is as much or more forward migration of the mandibular teeth. Without the latter to aid in treatment, correction of a Class II molar relationship would indeed require an incredible amount of maxillary tooth movement.

The conclusion is inescapable that orthodontic correction is largely made possible by satisfactory developmental growth. This, the Bolton Study has termed "the sequential changes with the passage of time". With these changes we enjoy a successful orthodontic result; without them we are disappointed, treatment lags, compromises must be made both as to methods and as to results.

Limitations of Treatment

It has been found that I can not forecast the effectiveness of extraoral treatment for the individual and this is what has led me to the six-month limit on application of this method. Even assuming the patients' eager cooperation I frequently find it necessary to change to fixed appliances.

Another limitation is the excessive time required in some instances. By hindsight I can recognize a number of cases where other methods should have given equal satisfaction in significantly less time.

A third limitation is in reality peculiar to myself, the operator, rather than to the method. This is the tendency to apply it to too severe malocclusions.

Auxiliary Anchorage

As many of you have no doubt long since learned, and as others have shown, perhaps the best use of extraoral force is in conjunction with other appliances. Its use can reduce the duration of Class II intermaxillary force and thereby lessen drastically the resulting anterior movement of mandibular teeth. It can also effectively reinforce intermaxillary elastics.

Extraoral force may be regarded as a useful orthodontic method in selected cases. That is, it may, given ideal patient cooperation and a satisfactory growth trend, adequately correct the relatively mild Class II, Division 1 malocclusions. In my hands it has become most useful as an auxiliary with other appliances. It may tip teeth severely when used alone but, almost invariably, they recover their original posture. It has not gained for me the dramatic soft tissue changes claimed by some.

Case Reports

Patient T. D. (#68) exhibited a moderately severe Class II, Division 1 malocclusion as judged from the occlusal relationships at his age of eleven years and five months. Dentally, the

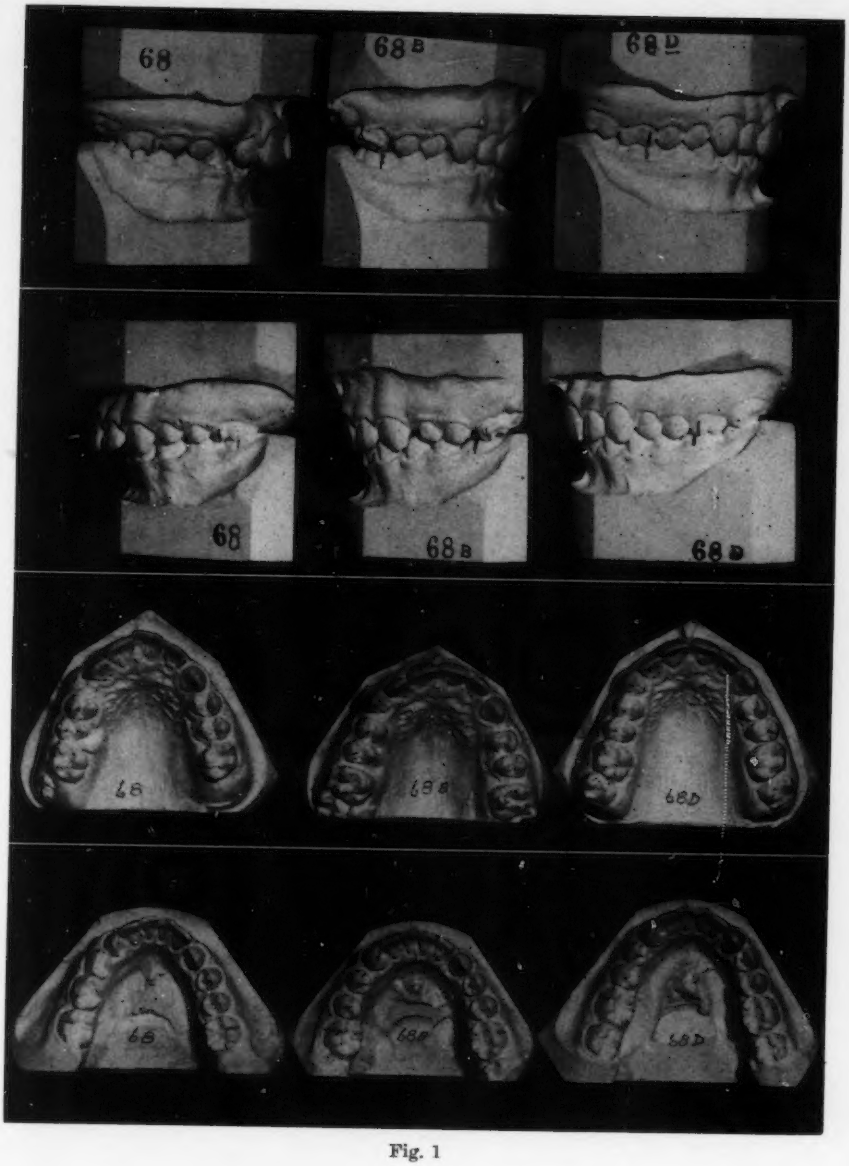

Fig. 1

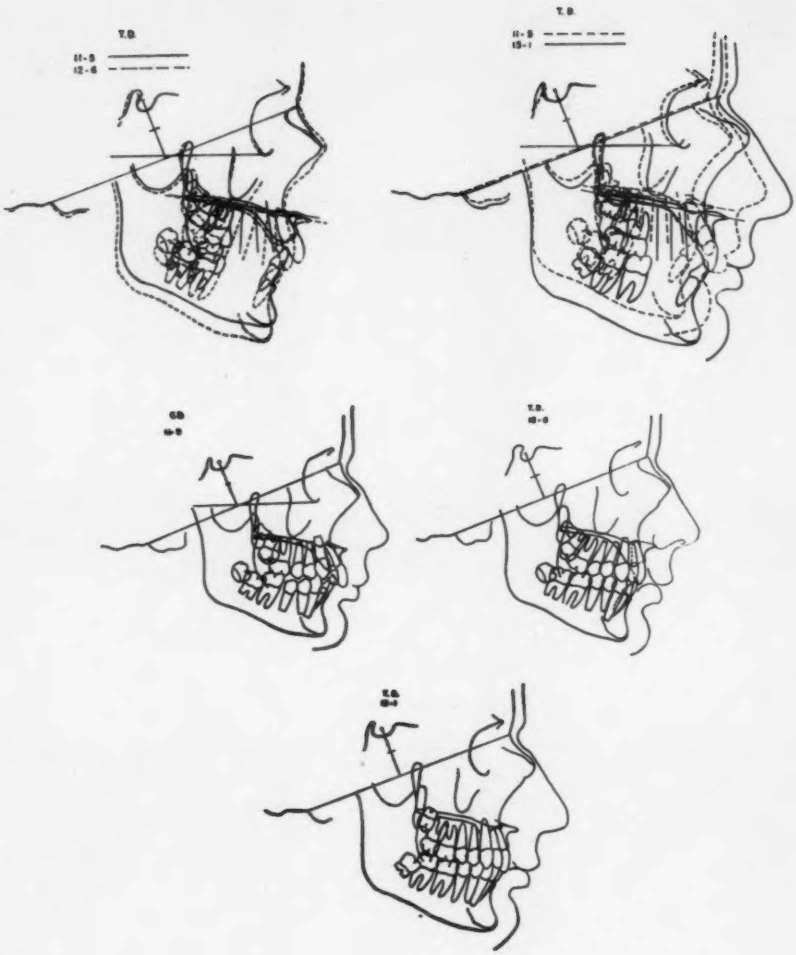

Fig. 2

two remaining deciduous teeth placed him in the terminal stage of the mixed dentition. Facially, there was little if any hint of the malocclusion although he appeared to lack vertical development (Figs. 1, 2 and 3). T. D. was a large boy, quiet and reserved.

The primary aim was to gain maxillary arch length for the partially blocked canines and the rotated incisors; correction of the Class II occlusion would realize this aim and should also reduce the overbite.

The cervical gear was installed in March 1952. The soldered facebow carried stops at the molar tubes which served to keep the incisors free and to concentrate the cervical force on the molar teeth. The molar stops were moved posteriorly several times during treatment. Three months after starting treatment a biteplate was installed to remove interference between the upper and lower incisors. As treatment progressed, the maxillary molars tipped posteriorly and spacing appeared between the buccal teeth. The molar tipping required adjustments of the inner archwire, to raise it anteriorly. In March 1953, the cervical gear was removed since an obvious over-correction had been gained. The biteplate was continued an additional three months and then removed. There was no other retention measure. At the time the cervical force was ended, the patient was instructed in the masseter-temporal exercise, and the benefit of vigorous mastication was emphasized. Cooperation was excellent throughout. The final records were made twenty-eight months after removal of the biteplate.

The following may be observed in comparison of tracings before treatment with those made at the end of treatment:

1) Extreme posterior tipping of all maxillary teeth.
2) Anterior movement of all maxillary root apices.
3) Extreme elongation of the maxillary six-year molars.
4) A downward and backward rotation of the mandible.

The following may be noted in the tracings made from x-rays taken twenty-eight months after removal of the biteplate, thirty months after cervical force was discontinued:

Fig. 3

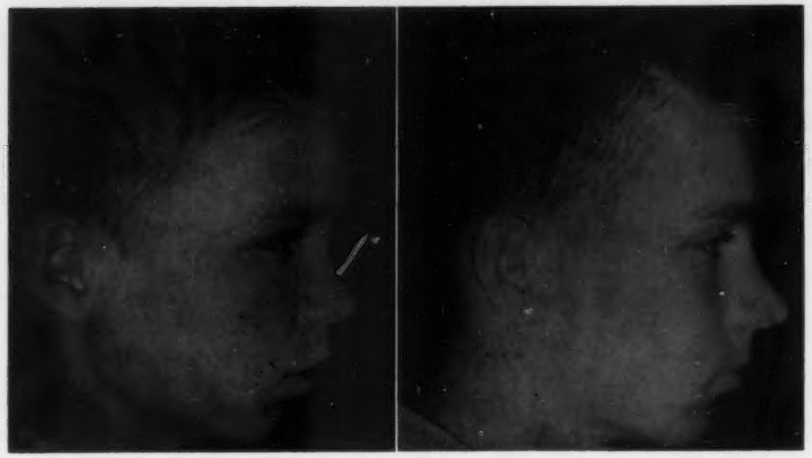

Fig. 4

1) Excellent facial growth; this carried all dental structures anteriorly and down.
2) Recovery of all tooth positions to substantially their original postures.
3) Minor soft tissue changes.
4) Loss of some of the overbite correction.

This patient is an example of a rapid response and a satisfactory result more than two years after removal of all appliances.

Patient R. G. (#104) was twelve years and four months of age at the time the original records were made in October 1949. The pre-treatment x-ray was taken by a roentgenologist and the tracing from it is not, therefore, strictly comparable with the other x-ray records taken with the Broadbent-Bolton cephalometer installed in my office in 1950. This also explains the absence of the Frankfort horizontal plane in the tracings of this case (Figs. 4, 5 and 6).

R. G. exhibited a severe Class II, Division 1 malocclusion and a recessive facial appearance. The lower incisors were procumbent. There was more than the usual "soul searching" on my part with regard to the advisability of removing bicuspid teeth and treating with full appliances. The decision was made to start treatment with the headcap with the "hedge", accepted by the parents, that extractions were a probability. This decision was reached by my estimate of a satisfactory growth potential but was also based on my reluctance, at that time, to remove bicuspids for orthodontic purposes. A biteplate was added about fourteen months later.

After two years of headcap treatment substantial correction had been gained but the maxillary second molars showed a pronounced posterior inclination. Consultation with another orthodontist resulted in the decision to remove these teeth. This was done in March 1952. Extraoral force was continued another three months but the biteplate was worn until December 1952. At this time, nine months after extraction of the maxillary second molars and six months after the extraoral force was ended, a third x-ray was made. The patient was then fifteen years, five

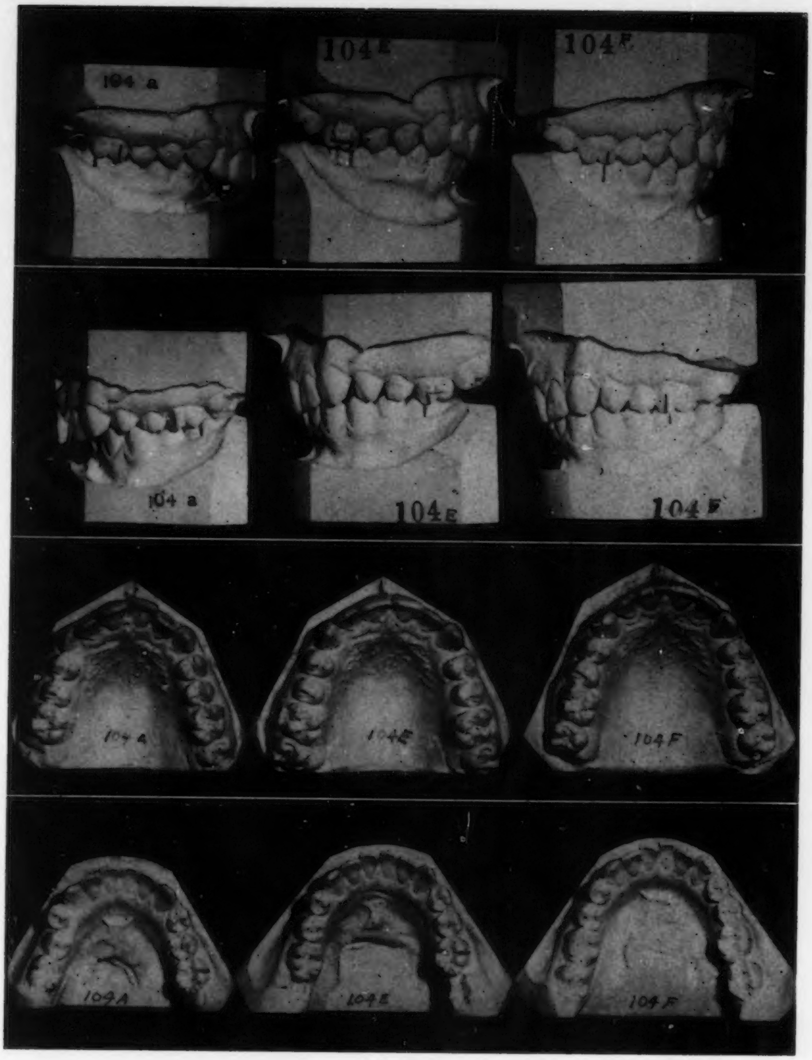

Fig. 5

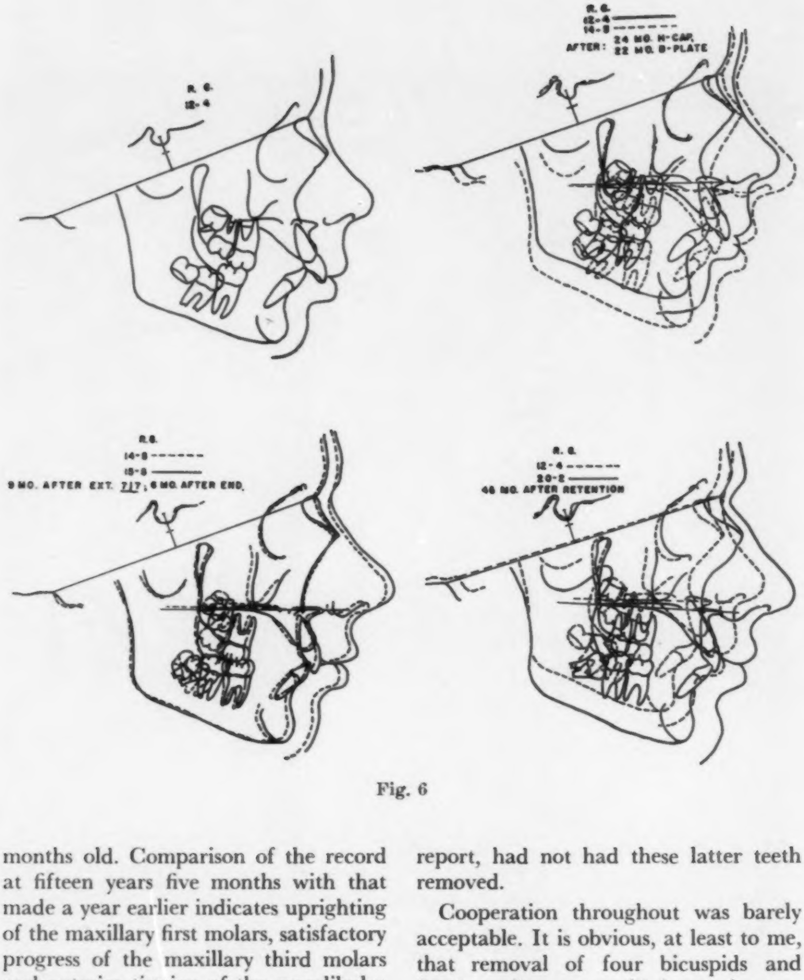

Fig. 6

months old. Comparison of the record at fifteen years five months with that made a year earlier indicates uprighting of the maxillary first molars, satisfactory progress of the maxillary third molars and anterior tipping of the mandibular third molars.

Almost five years after the biteplate was removed, the final records were made. Facially and occlusally there had been substantial improvement, but the recessive face remained. The maxillary third molars had appeared and were in functional position but the mandibular third molars were horizontally impacted. The patient, at last report, had not had these latter teeth removed.

Cooperation throughout was barely acceptable. It is obvious, at least to me, that removal of four bicuspids and fixed appliances would have given as satisfactory a result and in less than the thirty months required with extraoral treatment. Today I rarely consider extraoral treatment alone in such severe malocclusions.

Patient V. S. (#77) was eleven years and eight months of age when the original records were made early in 1951. She was a slender girl, very composed, who exhibited a relatively mild

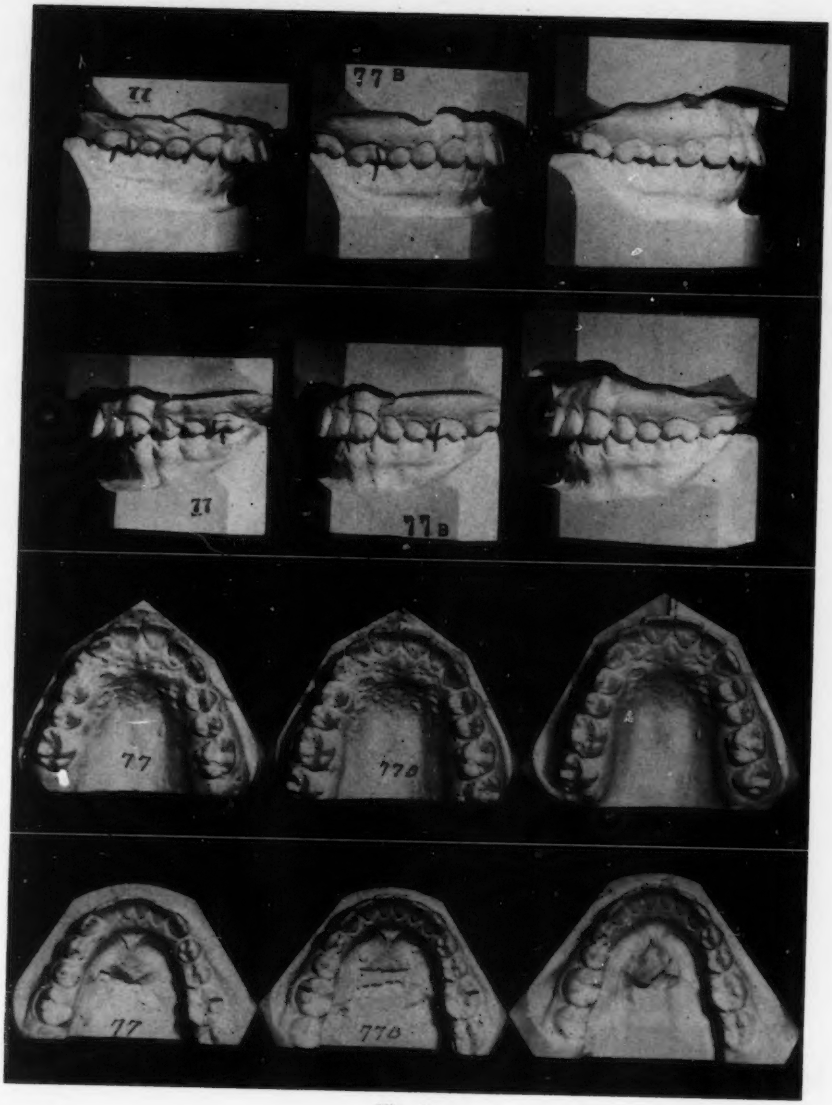

Fig. 7

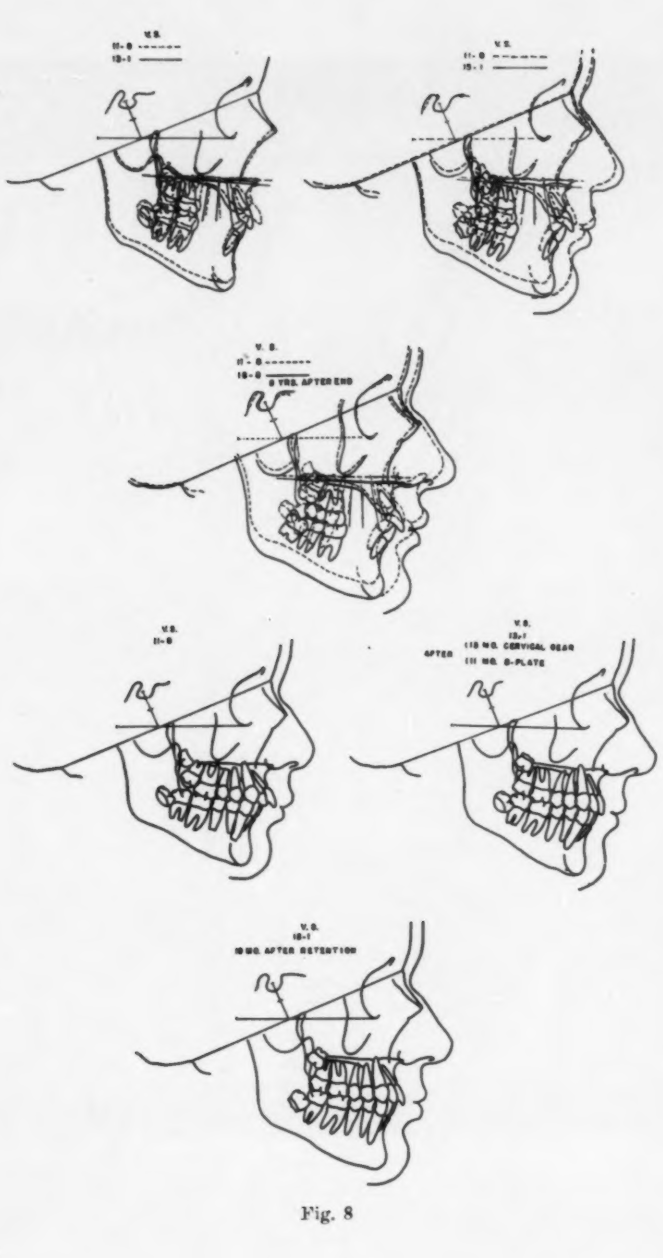
V.S.
V. S.
5 YRS. AFTER END
V.S.
V.S.
AFTER
CERVICAL GEAR
V. S.
AFTER RETENTION

Fig. 8

Fig. 9

Class II, Division 1 malocclusion (Figs. 7, 8 and 9). The maxillary anterior teeth were spaced. The cervical gear was installed in March 1951; the facebow was permitted to rest against the incisors (the inner arch carried "preventive" stops just anterior to the molar tubes) as an initial space-closing measure. A biteplate was placed three months later but was removed after eleven months.

Posterior tipping of the maxillary first molar roots became apparent clinically after seven months of treatment. To correct this, two adjustments were made raising the posterior ends of the facebow. As can be seen in the tracings, these adjustments were without effect and this undesirable maxillary molar inclination was maintained subsequent to removal of the appliance.

The cervical gear was removed in November, 1952, twenty months after starting treatment; during the last three months the gear was worn only on alternate nights. The final records were made in December, 1957, more than five years after treatment ended.

Patient K. B. (#389) was a girl of twelve years and seven months when the original records were made in the early fall of 1953. This relatively mild Class II, Division 1 malocclusion was complicated by a still-active thumb-sucking habit, indulged at night (Figs. 10 and 11). A cervical gear was placed in October 1953; the force was distributed over the maxillary denture, the molar stops being so placed that the facebow rested on the incisors and the stops contacted the molar tubes.

On the right side satisfactory progress was noted in a few months but there was no improvement on the left side. A biteplate was installed six months after start of the cervical gear but was worn indifferently. A year after the start, insufficient progress resulted in a consultation with the parents during which the need for full appliances was explained and the patient's promise to cooperate in wearing Class II elastics was finally gained. There followed a period of several months during which

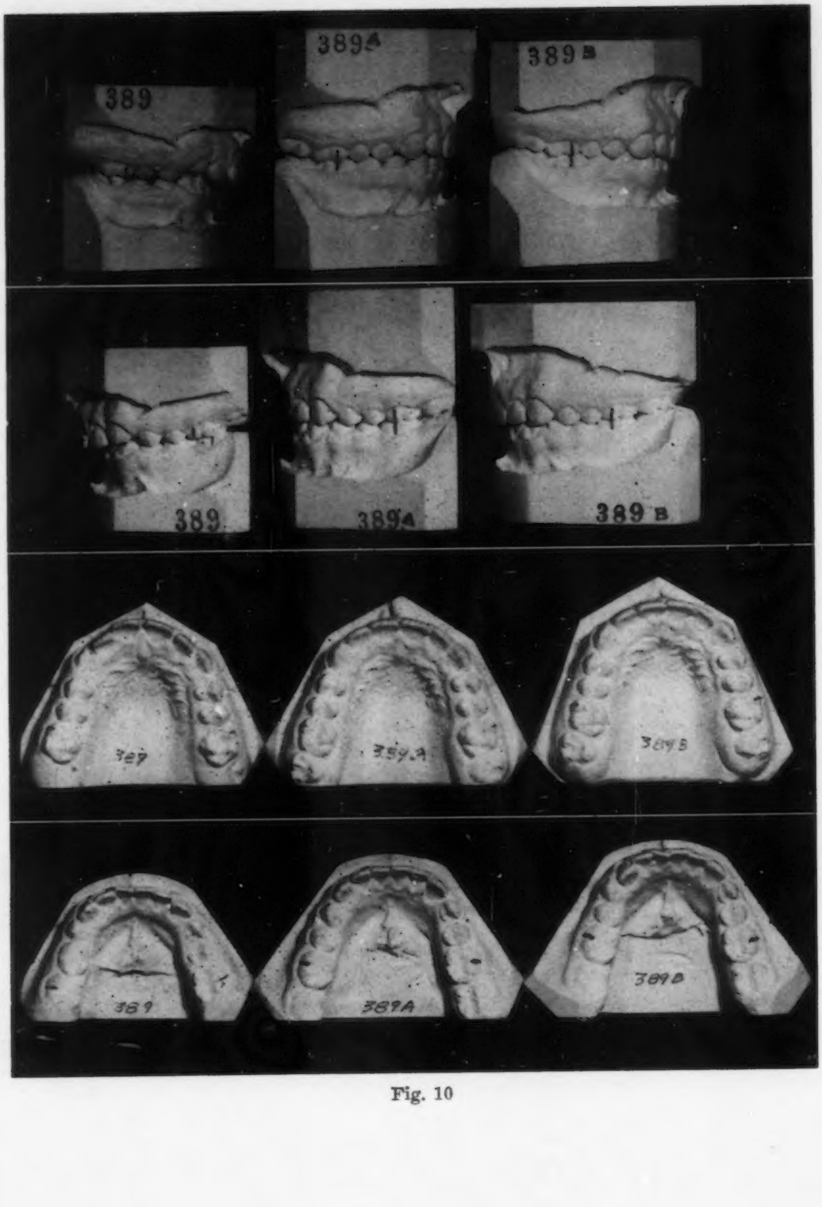

Fig. 10

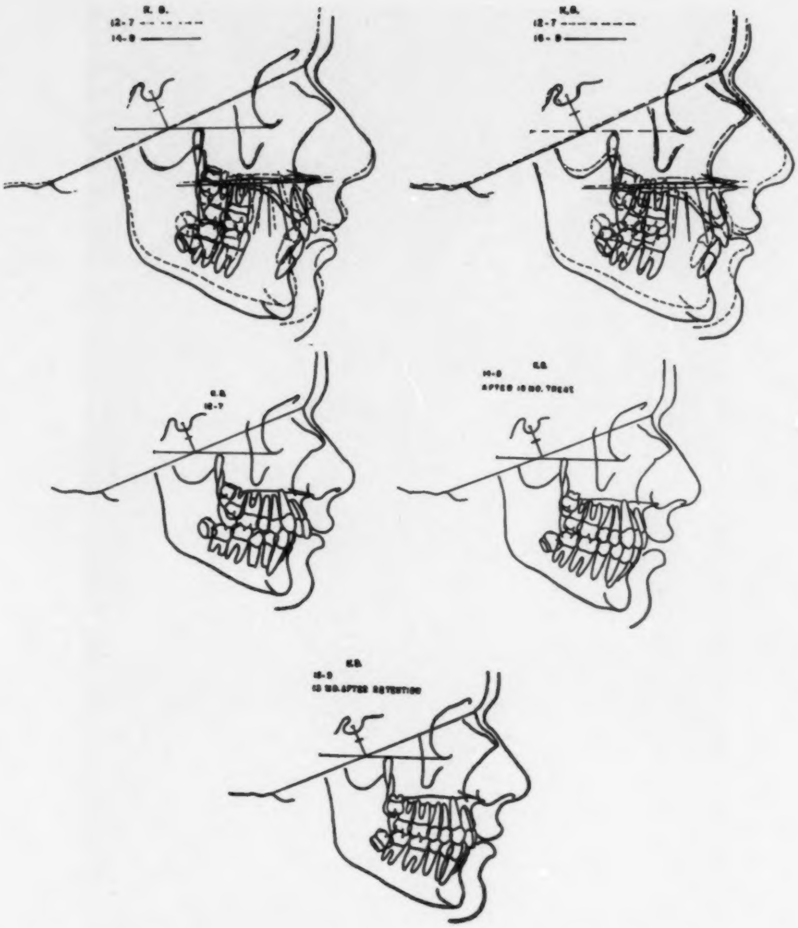

Fig. 11

nothing was heard from the patient as to the proposed additional treatment. Finally, the decision was made to continue and edgewise appliances were assembled in February and March of 1955. Routine Class II treatment required five months and the correction was retained with a biteplate in October 1955. Retention ended in August 1956 when the patient lost the retainer.

The thumb habit ended spontaneously during treatment.

Final records were made in September 1957, thirteen months after removal of all appliances.

In this instance a plateau of correction was gained with the cervical gear

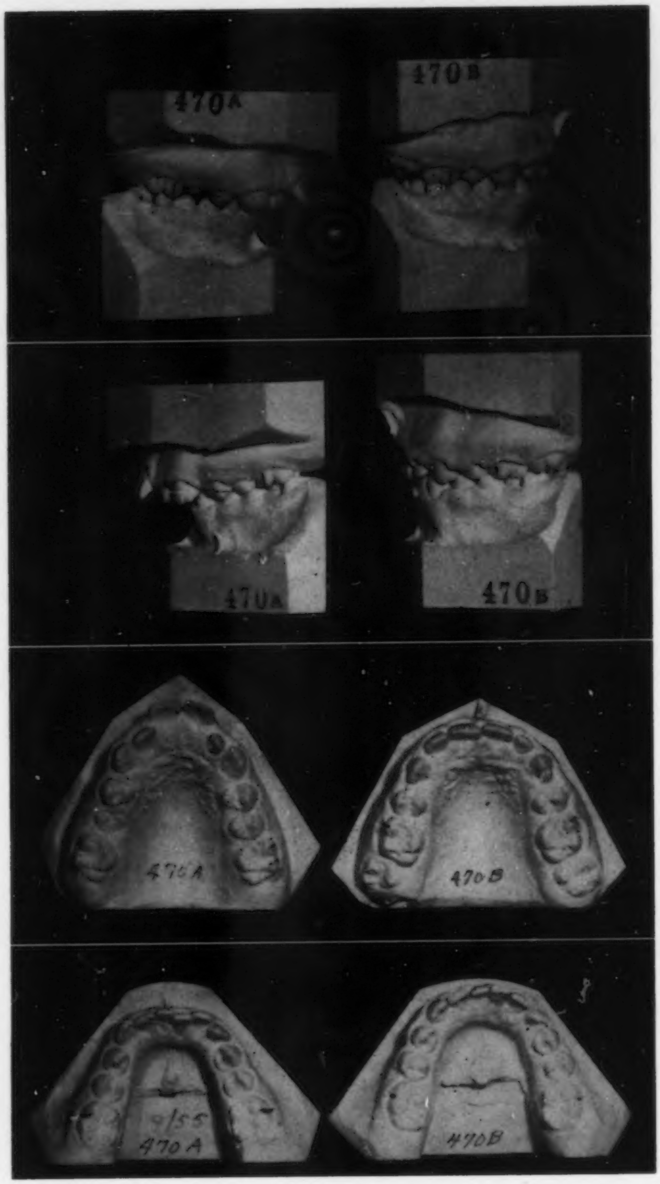

Fig. 12

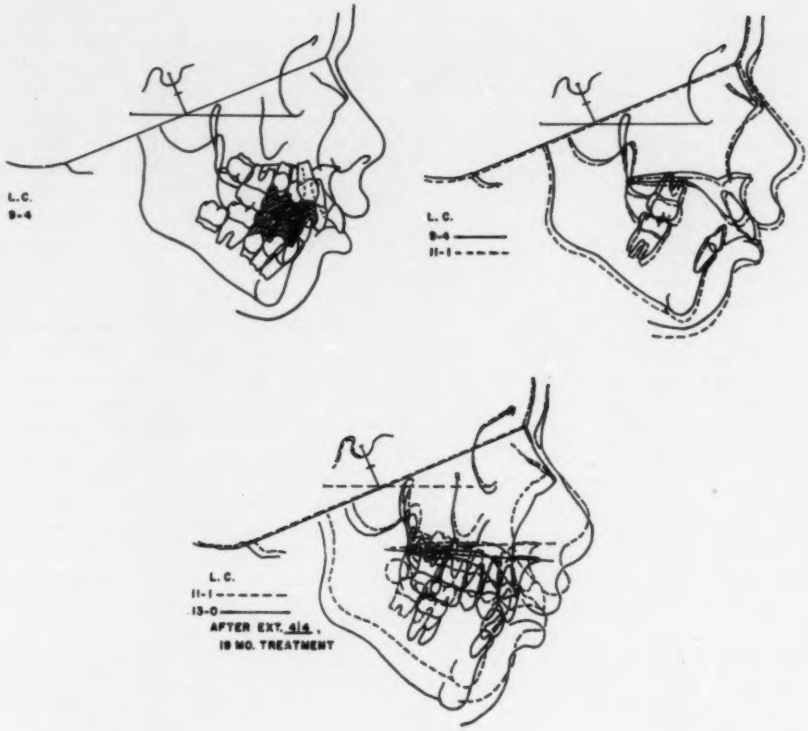

Fig. 13

which was significantly short of my goal. Satisfactory correction required fixed appliances, but this could have been gained, I believe, with the patient's cooperation with the cervical gear.

The next two patients are presented as examples of the use of the cervical gear in combination with fixed appliances. In the first of these the cervical gear was worn throughout treatment except the last two months when Class II elastics replaced it. In the second patient the gear was used as the only appliance at the start and was then replaced with fixed appliances.

Patient L. C. (#470) was a girl of nine years and four months when the first records were made in October 1953. She had a severe Class II, Division 1 malocclusion in the mixed dentition, a recessive chin, some loss of mandibular arch length and marked protrusion of the maxillary anterior teeth. The original x-rays indicated extreme facial growth handicaps in all respects (Figs. 12 and 13). Because I find extractions necessary in such cases and because I do not sacrifice permanent teeth until they have erupted clinically (on the theory such extractions may hinder facial growth), an observation period was advised.

A second set of records was made in August 1955. This was almost two years after the originals were made; the

patient was now eleven years and one month of age. Superposed tracings of the x-rays indicate minor facial and cranial changes; the trend of growth was vertical and the protrusion was increased.

In view of the severe malocclusion and the unfavorable growth trend the following treatment plan was adopted:

1) Accept Class II molar relation.
2) Extract the maxillary first premolar teeth.
3) Retract the maxillary anterior teeth.
4) Use cervical gear throughout.
5) Attempt to gain mandibular arch length.

Unavoidable delays postponed extraction of the maxillary bicuspids until January 1956. A cervical gear was worn at night; the maxillary cuspids were retracted with push coil springs on arch sections. The maxillary incisors were then retracted with closing loops. In the final two months of treatment, Class II elastics replaced the cervical gear. Active treatment was concluded in June 1957, after seventeen months of treatment, with the placing of a biteplate and a mandibular lingual wire between the cuspid bands. The patient is still under retention.

Records made at the end of active treatment indicate satisfactory retraction of the maxillary anterior teeth with the cuspids occupying the positions of the first bicuspids; there was incomplete closure of the extraction spaces. The maxillary posterior teeth were maintained in an upright position. There were marked vertical changes but gnathion is less prominent. The soft tissue changes were minor. The future of this patient can only be regarded with orthodontic pessimism.

Patient J. M. (#227) was a compact, stocky girl of twelve years and three months when her original records were made in January 1955. She was a composed and very cooperative patient whose face gave no outward hint of the Class II, Division 1 malocclusion. The latter was assessed as an anterior migration of the maxillary buccal teeth resulting in reduced space for the cuspid teeth. There was a diastema between the maxillary central incisors (Figs. 14 and 15).

A cervical gear was placed, in April 1955, carrying molar stops to keep the incisors free. Thirteen months later an edgewise appliance was placed, and the cervical force discontinued, to close the spacing of the buccal teeth and to align the anterior teeth. In the fall of

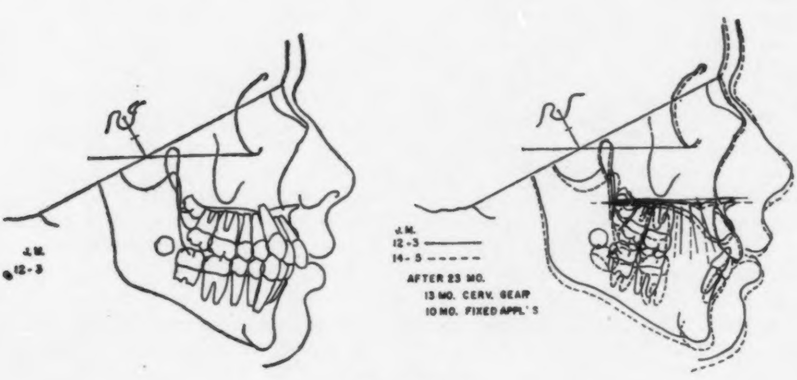

Fig. 14

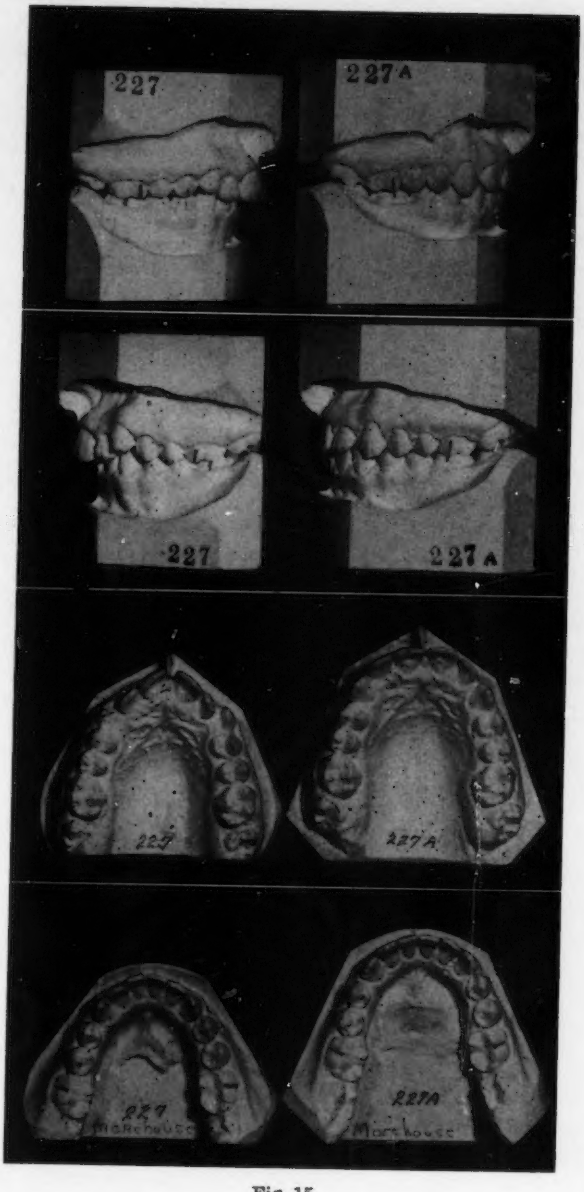

Fig. 15

1956 it was necessary to use Class II force; consequently a partial fixed appliance (mandibular first molars and the six anterior teeth were banded to receive an edgewise archwire) was placed. Class II elastics were worn for five months and the case retained in March 1957. The patient remains under retention.

Superposed tracings of the before and after x-rays show the following changes:

1) Bodily movement posteriorly of the maxillary first permanent molars and second bicuspids.
2) Posterior tipping of the maxillary third molars, second molars, first bicuspids and cuspids.
3) Elongation of all buccal teeth.
4) Anterior movement of all mandibular teeth.

Total active treatment time was twenty three months.

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Statistics: A Review*

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INTRODUCTION

The orthodontic literature has, in recent years, taken on the "statistical look." Where before-and-after photographs were once deemed sufficient proof of a technique, and tabulations were held capable of telling their own story, a whole system of notations embellishes papers of today. To comprehend them the reader must be familiar with $\overline{X}$ and x, N and $N!$, Φ and ρ. He must distinguish Z from z, t from T, and σ from Σ. He must, moreover, be cognizant of the special meanings of "significant," "correlation" and "association," and the statistical usage of the words *population* and *sample*.

Some research workers have reacted against statistics, as needless exercise, quoting perhaps the old adage "lies, damn lies and statistics." The late Ales Hrdlička, dean of American physical anthropologists, was certain that statistics would be the ruination of physical anthropology! And it is true that inexperienced workers have, on occasion, become overawed by statistical techniques and overly impressed by correlations and differences that attained the magical status of "statistical significance." Any series of measurements must have a mean, nearly all will have some dispersion. The use of statistics need not be confused with the practice of magic.

*Grateful acknowledgment is made to the author for this paper written at the request of the Editor. It is hoped that it will serve as a reference article for clarification of the statistical terms used in many papers.

**Fels Research Institute.

STATISTICS, STATISTICS, AND "STATISTICS"

In talking about statistics it is well to remember that the term "statistics" encompasses a number of different processes, some familiar and others less familiar. Statistics, for example, often refers to tabulation or enumeration. In the original sense this is what statistics meant, a usage we still preserve in the term "vital statistics," i.e. economic and demographic data tabulated by year, municipality, etc.

Statistics often means documentation or proof, as against a general and numerically unsupported assertion. If we wish to claim that treatment X is superior to treatment Y, we may refer to the "statistics," i.e. the figures that serve as proof.

Statistics may also mean measures of central tendency or dispersion. The mean, the standard deviation, the semi-interquartile range, etc. are all statistical measures.

Statistics, in the sense that it is most often used in the professional literature, refers to tests of significance, that is, methods that provide betting-odds as to the extent that a difference (or correlation) could have come about by chance alone.

Finally, statistics includes measures of correlation, like r and ρ, measures of association like χ^2 and *C.C.*, and measures of within-group variance and between-group variance, as in *analysis of variance*.

Thus, instead of a single bogey or idol called statistics, there are numerous 'statistics', each having its own place as a research tool, as a precautionary measure, or as an adjunct to data collection and data presentation.

Elementary Statistical Language

In the course of research one ordinarily makes a series of measurements, each designated by the small letter x, on a number of individuals, represented by capital N. The simplest and most-used calculation, the arithmetic average or mean ($\bar{X}$) thus involves summing (Σ) the individual measurements (x) and dividing by N. In mathematical shorthand therefore . . .

$$\S 1. \quad \bar{X} = \frac{\Sigma x}{N}$$

Now an exceptionally industrious orthodontist might desire to measure the bimolar diameter on every fourteen year old boy in America, or perhaps New York City. The average or mean would then be the *true* mean, the mean of the *population* itself. Ordinarily, however, our orthodontist would have to content himself with a portion of all individuals he could conceivably measure, i.e., a *sample* rather than the *population.*

Such a sample might be obtained by picking subjects at random (a *random sample*); or it might be a *stratified sample* (including subjects from each ethnic and socio-economic group). But in the latter two cases, especially if the number of subjects is not large, the *obtained* mean might differ from the *true* mean, due entirely to accidents of sampling (the *sampling error*). Many statistical calculations involve estimating the likely limits of the sampling error.

In presenting his data our worker would have the problem of computing (a) measures of *central tendency,* and (b) measures of variability or *dispersion.* He is faced, as we have seen, with estimating the magnitude of the *sampling error.* Very likely, he will be interested in the *correlation* among several measurable variables (such as lengths *SN, NGn,* and *GnGo*), or the association between such attributes as breast-feeding and an Angle Class II occlusion.

Measures of Central Tendency

Research, as we have said, is commonly productive of measurements, and the first need is usually to do something with a long string of such measurements. Except for rare individuals and exceptional measurements, such a series can not be committed to mind. Rare too, is the editor who will allow his pages to fill with raw data. First and foremost there is the need to summarize the findings in a single number or by a number or two.

The simplest and most convenient measure of "central tendency" is the familiar average, better called mean or the "'arithmetic mean" (to distinguish it from the geometric mean). The mean has many virtues, including the following three:

1. The mean is easily calculated (as in formula §1) by summing-up individual measurements and dividing by N. Arranging values from least to most, or first grouping them into class intervals is not a necessary prerequisite.

2. As the most used measure of central tendency, the mean is the point of departure for the standard deviation (SD or σ), and the standard error of the mean ($se_{\bar{x}}$).

3. Any series of measurements automatically yields a mean. Practically everybody has at least a rough idea of what the mean is supposed to represent.

However, the mean has a number of limitations of which the following two should be stressed:

1. The mean is a hypothetical value; average the stature of one giant and one dwarf and you have a perfectly good mean that represents neither.

2. The mean is highly influenced by extreme values. A millionaire classmate markedly elevates the average income for the class of '28.

In contrast to the mean, therefore, which is most applicable to a symmetrical "normal" or nearly-normal distribution (see Figs. 1 and 2) the *median* (or mid-point of a distribution) has certain advantages. The median is easily determined; it is the middle value of an odd set of numbers, 4 in the following sequence . . .

1..2..3..4..5..6..7

or the mid-point in an even number of values, such as . . .

1..2..3..4..5..6

where the median is then 3.5.

In the sequence 1,2,3,4,5,6,7,8,30 the

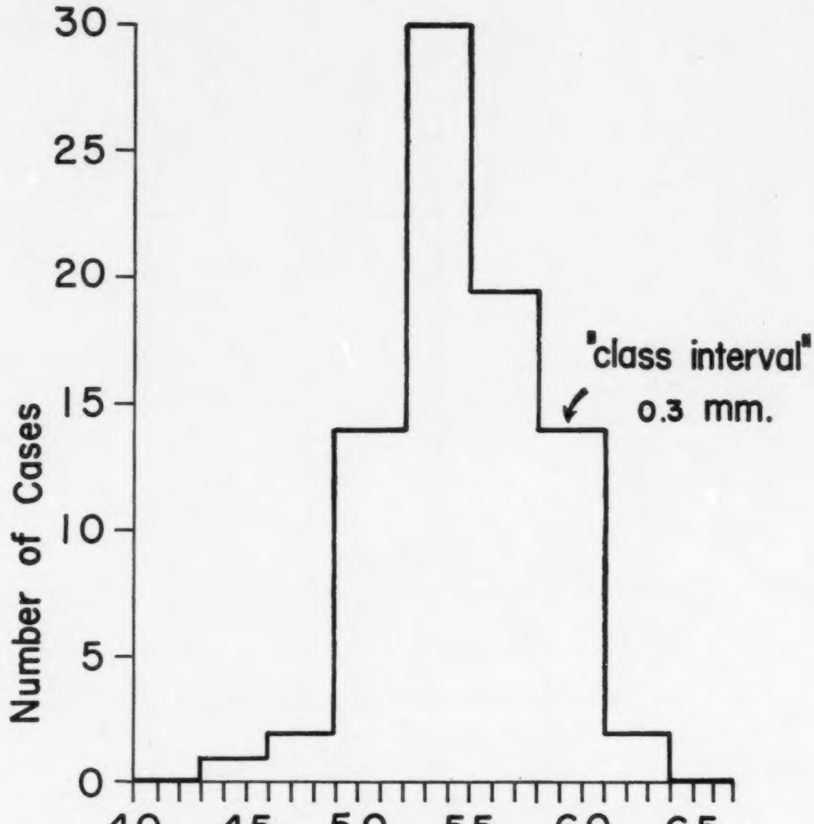


Fig. 1 Frequency distribution of mesio-distal diameters of I_1 using "class intervals" of 0.3 mm. Most of the values cluster between 5.0 and 6.0 mm. Only a few are found at the "tails" of the distribution. (Data courtesy of C.F.A. Moorrees)

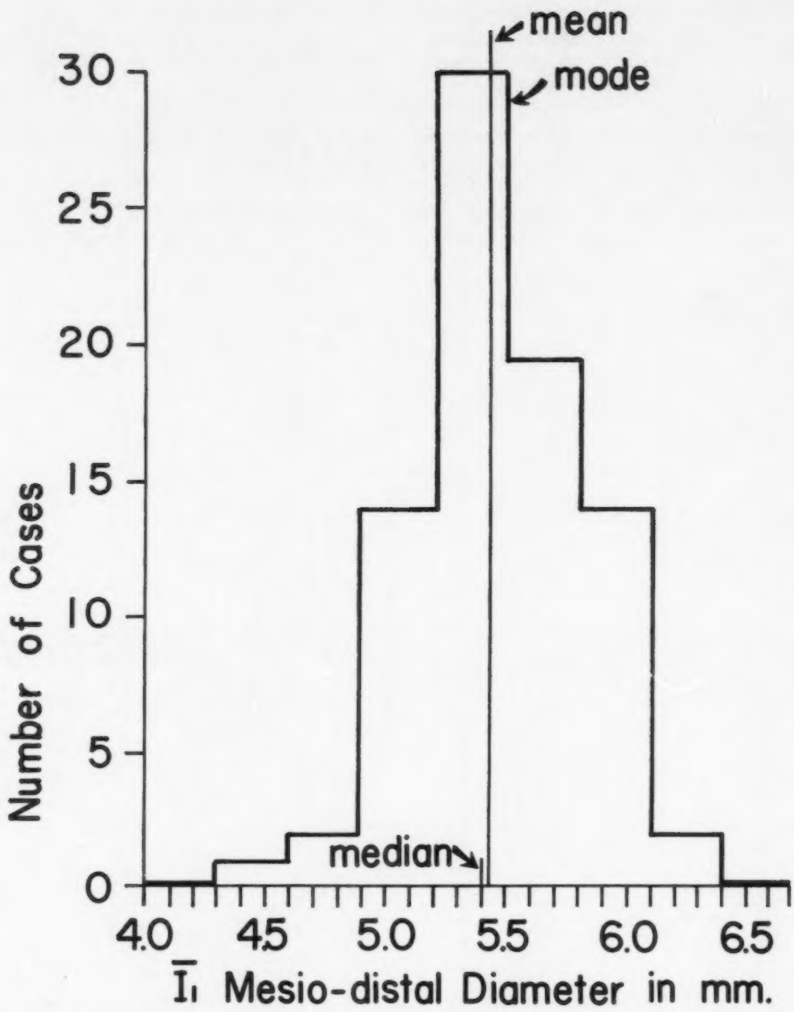


Fig. 2 Frequency distribution from figure 1 showing the location of the mean, median and mode. In this distribution there is a slight skewness and, therefore, a small difference between the mean and median.

median is 5; the median is thus a better indication of central tendency than is the mean when *skewness* exists to a marked degree.[1]

However, measurements used by the orthodontist: tooth size, facial breadths,

[1] A skewed distribution is not symmetrical about the median, but has a long "tail" either to the right or to the left. Fat and measures including fat, such as weight, generally have a long tail to the right and are therefore said to be "skewed" to the left.

roentgenographic diameters, etc. are essentially normally distributed, ordinarily with little skewness. The mean is most applicable to such distributions. Moreover, the standard deviation (σ) or (*SD*) is calculated about the mean and not the median. There are many tests of significance that utilize the mean, relatively few that are suitable for the median.

Finally, the mode, a third measure of central tendency, is of less value in quantitative analysis (Fig. 2). The mode, literally the most *common* or most *fashionable* value, has a particular place where the class-intervals are broad. Thus, income data on the class of '28 might be given as follows:

Annual Income, Class of 1928

Mean	$8,916.00
Median	8,600.00
Mode	8,000.00 - 9,000.00

Since the mode may represent a broad class-interval the following comparison may be made.

Teaching (all levels)	$7,000-8,000
Law	9,000-10,000
Business (all categories)	$9,000-10,000
Accounting	11,000-12,000
Dentistry	12,000-13,000
Medicine	15,000-16,000

The mean, then, is the most useful measure of central tendency for orthodontic research.[2] It is followed closely by the median, and at some greater distance by the mode. One warning should be made, however. Any series of measurements will have a mean (or median). Means or medians are merely measures of central tendency, not indications of what is right, proper or normal!

[2] This statement does not mean that the median is an inferior measure. Often, especially where distributions are skewed, the median is the preferred measure of central tendency.

Measures of Dispersion

Commonly, the research worker is interested in more than a measure of central tendency. Not only is the mean informative to him, he needs also indications of the extent to which individual measurements are "scattered" or "dispersed" about the mean. If the incisor-mandible angle is 90° within very close limits, it may have more diagnostic utility than if individual values range down to 80° or up to 115°.

Clinically, the "range" is much used, that is, the lowest and highest value in a series (arranged in increasing order of magnitude). The range as determined in a clinically-healthy population is frequently described as the "range-of-normal." However, the range is a deceptive and inadequate measure, changing as it does with sample size, and dependent on measuring errors as well. The larger the sample (N), the wider the range, simply because very small and very large individuals or measurements are increasingly likely to be encountered in large samples. And, since measuring and copying errors tend to throw values to the extreme ends of a distribution, the range is most likely to encompass such errors.

The most commonly-used measure of dispersion is the *standard deviation*, symbolized by *SD* or the lower case Greek letter sigma (σ). Simply, the standard deviation is *the root mean square deviation from the mean*. Thus, if the deviation (d) from the mean of each individual measurement (x) has been computed, the standard deviation is . . .

$$\S 2. \quad \sqrt{\frac{\Sigma d^2}{N}}$$

However, computing d for each measurement may be avoided by the assumed mean at zero technique in which σ is calculated as follows . . .

§3. $$\sqrt{\frac{\Sigma x^2}{N} - \left(\frac{\Sigma x}{N}\right)^2}$$

Since the standard deviation is the root mean square deviation from the mean, the limits —1 *SD* to +1 *SD* include 67% of cases (Fig. 3). Moreover, the ± 2 *SD* limits include 95% of cases. Thus, giving the mean, as computed in formula §1, and the standard deviation, as computed in formulas §2 and §3, provides basic information on both central tendency and dispersion. The ±2 standard deviation limits may be employed as the limits of clinical normality. Furthermore, such measures as the standard error, the coefficient of correlation, analysis of variance and many tests of

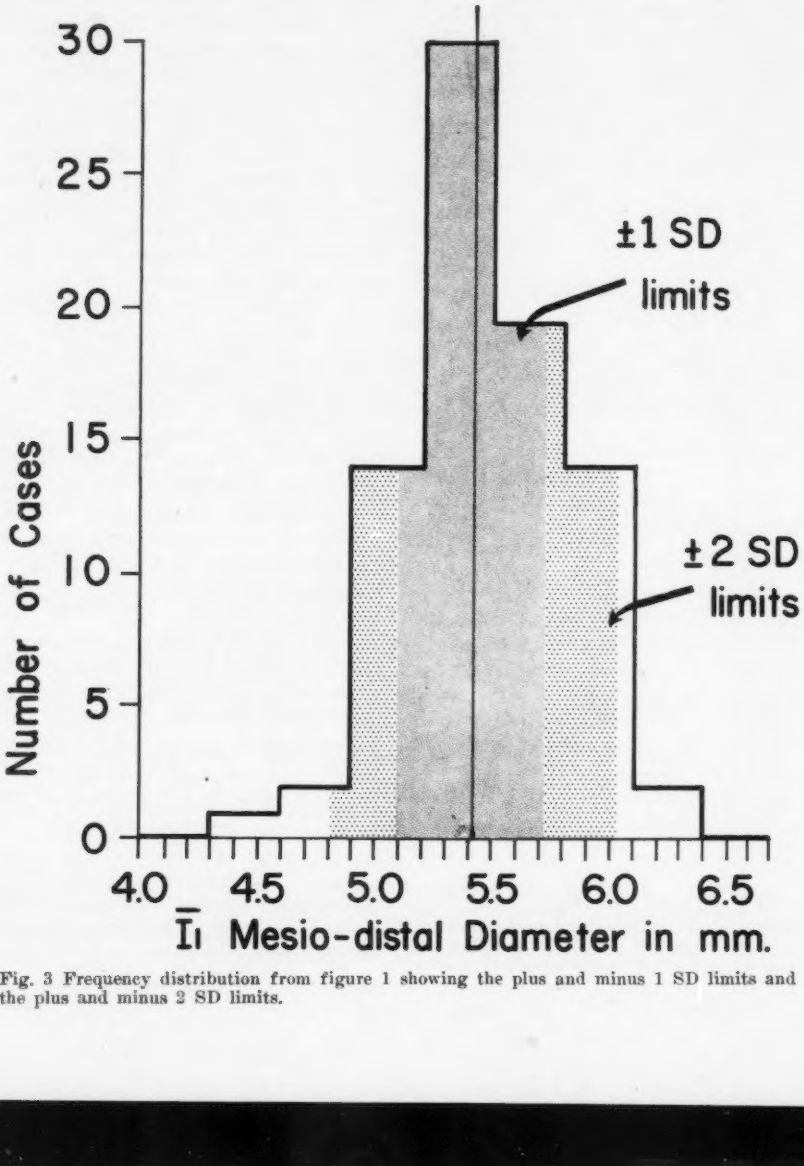


Fig. 3 Frequency distribution from figure 1 showing the plus and minus 1 SD limits and the plus and minus 2 SD limits.

significance employ σ in their computation.

Two limitations of the standard deviation must be noted, however. First, the standard deviation may not be meaningful to a purely clinical or to a lay audience; instead, percentiles may be given (see below). Second, the standard deviation is inappropriate for markedly *skewed* distributions, or in comparing distributions that differ in the amount of skewness. Fortunately, as mentioned before, most measurements likely to be encountered in orthodontic research are not markedly skewed in distribution.

Caries counts (the DMF), lactobacillus counts, salivary enzyme concentrations, the concentration of the secretor (S) factor do tend toward skewness, and in this event, skewness must be eliminated either by calculating the exact transform, or through such techniques as normalized *T*-scoring.

As a measure of dispersion the use of percentiles has much to recommend it, especially in presenting norms for clinical purposes. The 50th percentile for tooth eruption (the age at which 50% of children of one sex have erupted a given tooth), is easily understood, as are the 5th, 15th, or 25th percentiles. The 5th and 95th percentiles are useful because they may be taken as the limits of clinical normality; they correspond roughly to the ± 2 *SD* limits. Some workers prefer the 10th and 90th percentiles, especially in representing height and weight norms. And, if *quartiles* are to be used, the 25th, 50th and 75th percentiles are helpful values (Fig. 4).

A percentile value, while easily comprehended, need not correspond with any actual value in a distribution, especially in studies where children are examined at fixed intervals. For example, if 0% of infants show M_1 calcification at birth, and 100% do at 3 months, the 50th percentile is thus 1.5 months, i.e., the age at which 50% of the infants would have shown M_1 calcification if they had been examined at that age.

The standard deviation and corresponding percentile limits are measures of absolute variability; comparison may be made as long as the means are approximately the same. Thus $\overline{C}$ with a mean age of eruption (in the male) of 10.79 years and an *SD* of 1.27 years is obviously less variable than $\overline{P}_1$ with a mean age of eruption of 10.82 years and an *SD* of 1.47 years. Direct comparison with $\overline{M}_1$ ($\overline{X}$ 6.20, σ 0.80) cannot be made, however, because of the much earlier age of eruption of $\overline{M}_1$. In such an event the *coefficient of variation* (*CV*) is used, σ being expressed as a percentage of the mean . . .

$$\S 4. \quad \frac{100\,\sigma}{\overline{X}}$$

Thus, in the examples given above, the coefficient of variation for $\overline{C}$ is 12%, for $\overline{P}_1$ is 14% and for $\overline{M}_1$ is 13%. Clearly $\overline{P}_1$ is more variable in eruption than is $\overline{M}_1$.

The fact that the *CV* is based on the mean can lead to certain difficulties, especially where the mean is expressed in relation to an arbitrary zero. For example, the coefficient of variation for $\overline{i}_1$ and $\overline{i}_2$ eruption is excessively high when birth is used as the reference point, much more moderate if time-since-conception is employed. Here, the standard deviation is unaffected by the choice of a zero point while the mean is highly dependent on the reference point. Similarly, the *CV* for the basal metabolic rate is infinitely high if related to the arbitrary zero for "normal" BMRs; much more reasonable as expressed in relation to gross oxygen consumption.

MEASURES OF INDIVIDUAL POSITION

Measures of dispersion serve to indicate the extent of dispersion or "scatter" of individual measurements about the mean, and therefore (along with the coefficient of variation) express both the absolute and relative magnitudes of variability. A distribution with

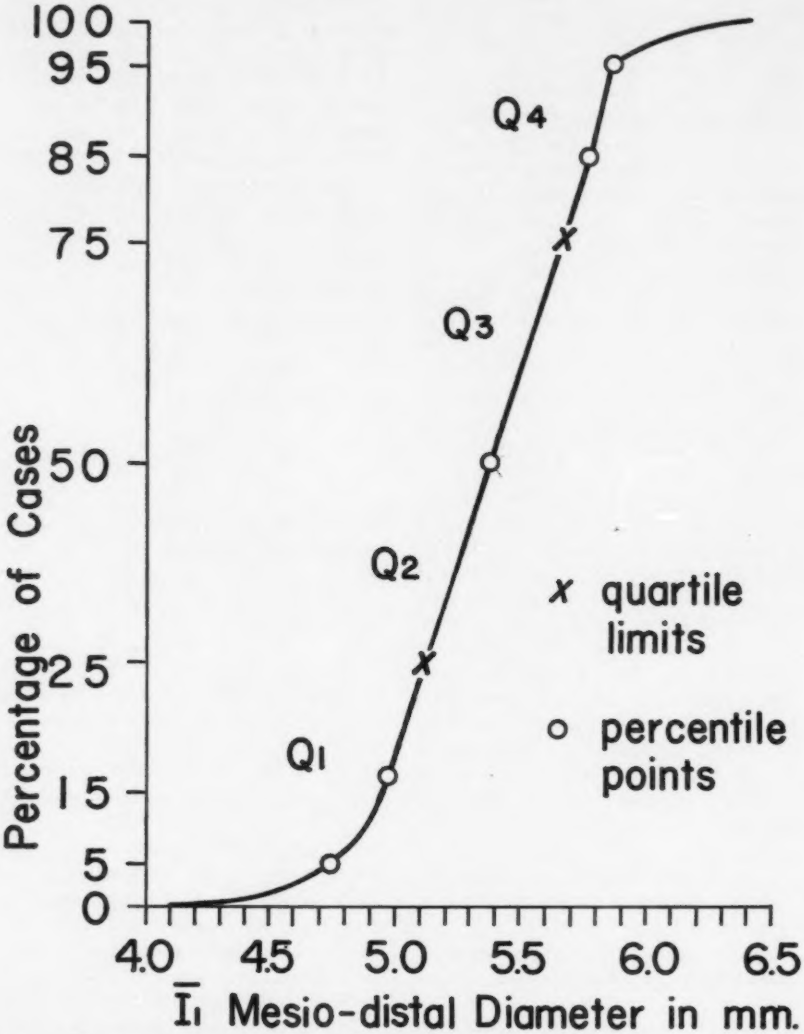


Fig. 4 Cumulative frequency curve for the data shown in figures 1-3. The 5th, 15th, 50th, 85th and 95th percentiles are shown by open circles. The limits of the four quartiles are similarly shown. From this curve the percentile position of any value from 4.1 to 6.3 mm. can be determined by interpolation.

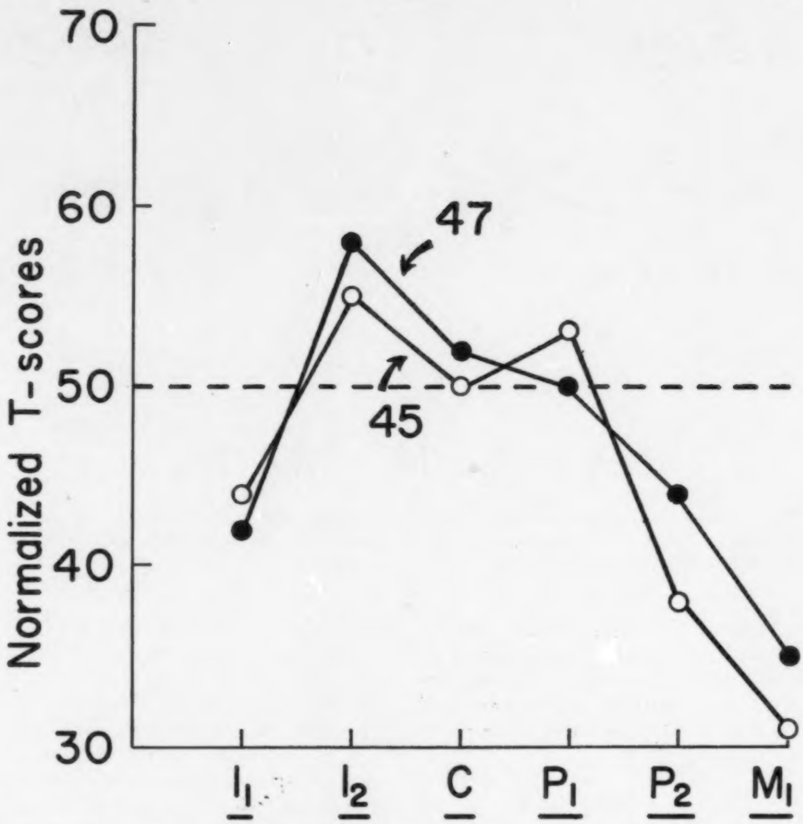


Fig. 5 Pattern profiles using normalized T scores for maxillary tooth size in a set of monozygotic twins. Note that the twins are closely similar patternwise. The use of T scores to provide an indication of individual position is thus shown.

a large *SD* is absolutely more variable than a distribution with a small *SD;* if CV_1 is greater than CV_2, then CV_1 has the greater relative variability.

The mean and the standard deviation, together with an individual measurement (x), can be used as a measure of individual position. All that needs to be done is to divide the difference between the individual measurement and the mean by the standard deviation; the result is the Standard Score or Z-score, and the formula for *SC* or *Z* is . . .

$$\S 5. \quad \frac{x - \bar{X}}{\sigma}$$

Thus an individual exactly 1 *SD* above the mean has a *Z*-score or Standard Score of +1, and so on (see Fig. 5).

The mean *Z* score is thus always 0, and the standard deviation of *Z* scores is therefore 1. Thus if the mean bizygomatic diameter for a series is 130 mm. with an *SD* of 6, a child with a bizygomatic diameter of 124 has a *Z* score of —1, whereas a child with a *Z* score of 0 is exactly at the mean. Since zero

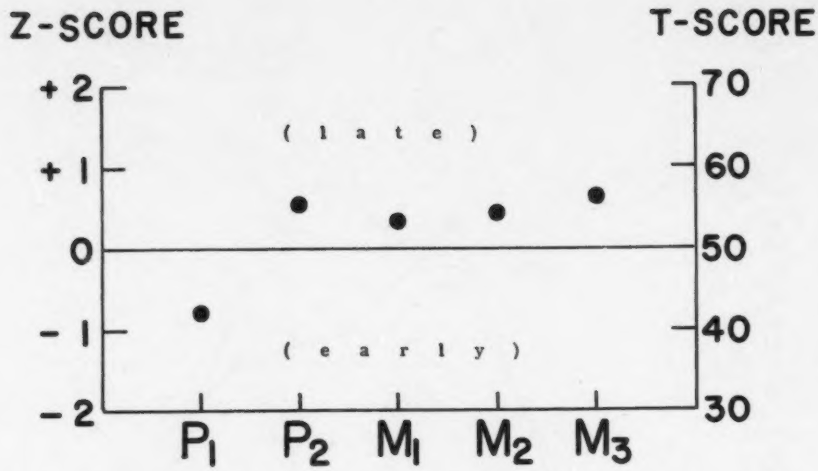


Fig. 6 Z-score or T-score plot of tooth formation in an individual child who is early in P_1 formation by nearly 1 Z score and late by 0.4 to 0.6 Z scores in the formation of the remaining posterior mandibular teeth.

is unliked as a mean value, and the use of both negative and positive *Z*-scores is cumbersome, *T*-scores are often used instead. To convert a *Z* value into a *T*-score value, multiply by 10 and add 50. Thus . . .

§6. $T = 50 + 10Z$

That is, *T*-scores have a mean of 50 and an SD of 10. *Z* or *T* scores are especially useful when many different measurements of an individual or group are to be compared as, for example, in the Hellman "wiggle" or in pattern-profile analyses (Figs. 5 and 6).

If an author publishes means and standard deviations, it is then possible, by simple subtraction and division, to compute the T-score or Z-score value of any given measurement.

On the other hand, if percentiles are given, some work may be saved. One merely has to determine, by comparison with the published data, which percentile value a given measurement falls nearest. Thus, if the 50th percentile is 130 mm. and the 85th is 136 mm., then a measurement of 135 mm. is close to the 85th percentile. The lack of calculations makes percentiles especially useful for rough clinical approximations, as may be seen in the following hypothetical comparison, where an orthodontist wants to look up a face length of 118 mm. . . .

I	II	
	mm.	*percentile*
$\overline{X} = 125$	115	5
SD = 5	120	15
	125	50
	130	85
	135	95

To compute *Z* or *SC* he must subtract 125 from 118 (−7) and divide by 5, a *Z* score of −1.2 or a *T*-score of 38 (i.e. −12 plus 50). Quickly, however, he can see that 118 falls midway between the 5th and 15th percentile or approximately the 10th percentile. However, for more exact calculations,

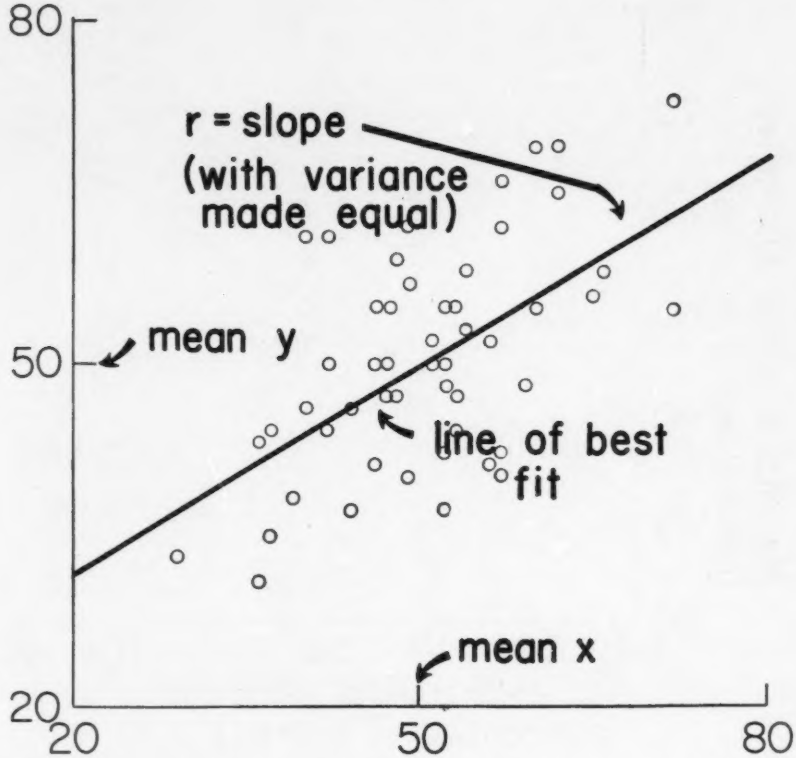


Fig. 7 A scattergram showing the relationship between the size of M_1 and M_2. Depicted are the trend line and the individual points.

further percentile data would be needed, or he would have to construct a cumulative frequency curve from the data in II, and then interpolate (as with Fig. 4).

Computing measures of individual position is not an ordinary prerequisite to reading or comprehending papers. However, if one wants to utilize published norms for the more detailed understanding of individual data, or for evaluation of a particular case, the concept of *T*-scores, *Z*-scores and percentile points is an important one to master.

Measures of Correlation

Measures of *correlation* are generally employed to test the degree of relationship between variables, such as the familiar measurements that can be fully quantified. It is also possible to use measures of *association* for this task, but with a considerable loss of information. Obviously, the child who is but slightly above average in cariousness differs greatly from the boy or girl who has a phenomenally necrotic dentition.

The most commonly used measure of correlation is the Pearsonian r; that

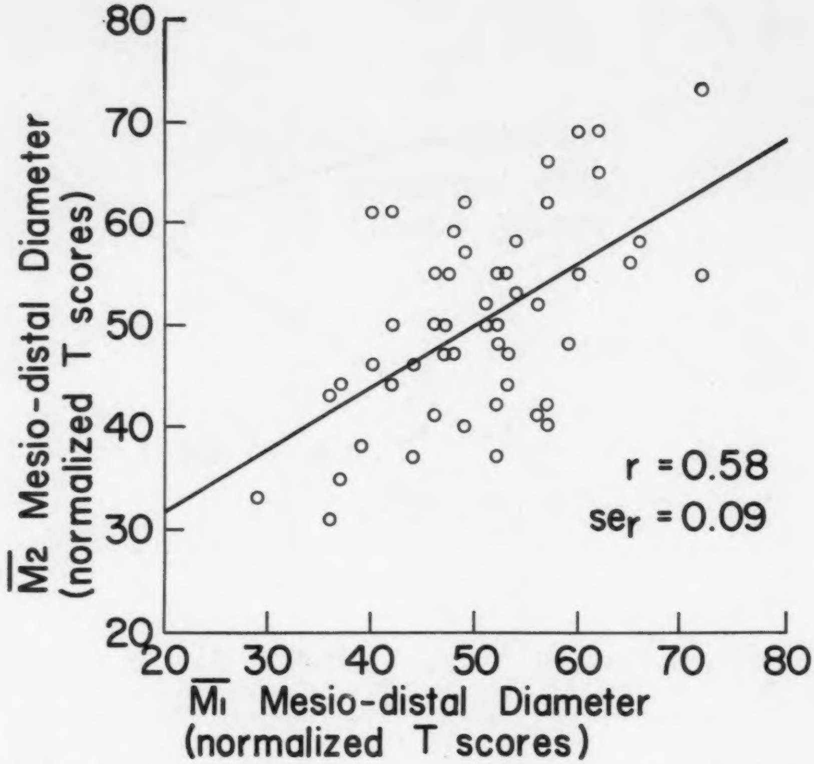


Fig. 8 The same scattergram as in figure 7 with the mean for the X distribution (abcissa) and the Y distribution (ordinate) and the line of best fit as determined by the goodness-to-fit formula.

is the product-moment correlation, or *Correlation Coefficient*, or simply "*r*". There need be no mystery about *r*; it is simply *the mean cross-product of standard scores.* An *r* of 1.0 means that if variable X goes up or down 1 Standard Score, so does variable Y and so on. In formula form . . .

§7. $$\frac{\Sigma SCx \cdot SCy}{N}$$

But, since it is most convenient to compute directly from the raw data (i.e. *raw scores*), the simpler but longer formula for *r* is . . .

§8. $$\frac{\frac{\Sigma xy}{N} - \bar{X}_x \ \bar{X}_y}{\sigma_x \ \sigma_y}$$

Obviously if σ_x and σ_y were each 1, as they are in standard scores, formula §8 would revert back to formula §7. And in either case *r* is merely the slope of the line of best fit, with variance (i.e. σ^2) made equal (see Figs. 7-8).

Now the value of *r* ranges from +1 (perfect positive correlation) through zero (no correlation) to —1, perfect negative correlation. For convenience

an r of 0.00 —0.39, is called "low", one of 0.40 to 0.79 "moderate" and one of 0.80 to 1.00 is called "high." The meaning of low, moderate and high, however, should be understood, in reference to r^2, for r^2 "explains" the percentage of interpersonal variance accounted for by the value of r in question. Thus for an r of 0.5, r^2 is 0.25; for an r of 0.7, r^2 is 0.49; for an r of 0.9, r^2 is 0.81.

An r of 0.5 accounts for only a *quarter* of the total interpersonal variance, one of 0.7 only a *half*, and even with an r of 0.9, approximately 20% of the interpersonal variance still goes unexplained.

The Pearsonian or Product-Moment r further applies only to certain types of distributions, and with equal-interval scales. Where normality, homoscedasticity, etc., cannot be guaranteed, the rank-order correlation rho (ρ) is preferable. Rho is one of the *non-parametric* measures of association and is . . .

§9. $$1 - \frac{6\,\Sigma d^2}{N\,(N^2 - 1)}$$

Rho may be applied with confidence to almost any data that can be ranked, and is thus useful in relating *degree* of malocclusion to other variables.

In certain cases, many of them unlikely in orthodontic research, r may not be applicable because the relationship between the two variables is nonlinear. Here the correlation ratio η may be tried, if η exceeds r by 0.1 or 0.2 η may be reported instead of r. But a more exact test involves the computation of epsilon squared (ϵ^2). Whether r, ρ, η, or ϵ^2 are used, the research worker must be careful on two accounts. First he must be careful to use the term "correlation" only in its more narrow statistical sense. Second, he must avoid confusing correlation with *causation.*

In popular language both association and correlation are referred to as correlation, or in the English usage, "corelation." Since, as we have known, simple association may exist without a very high correlation, it is both confusing and unnecessary to continue the confusion. If the tests for association and the tests for correlation are held clearly in mind, then confusion need not be furthered.

Much more difficult, however, is disassociating the notion of correlation (or association) from that of causation. This is difficult because the research worker ordinarily has causation in mind when he collects his data, and even before computing r or ρ. But the fact that Y varies with X does not mean that Y directly affects X. To begin with, the choice of Y and X are purely arbitrary. Y may affect X, or X may affect Y, or both X and Y may be affected by a common third variable Z. Y may affect Z and Z may then affect X. Or the whole relationship may be time-related, age-related, or merely fortuitous.

The number of teeth present in early life is positively correlated with body weight. Later, it is negatively correlated with weight. The number of criminals in American jails has risen almost linearly with cigarette sales; cigarette sales correlate neatly, over the years 1900-1950, with pig-iron production; pig-iron production and the number of orthodontists are similarly correlated. The correlations are true ones, being, in these examples, either age-associated or time-associated. But the relationships are hardly causal; orthodontists neither make iron ingots, nor are they created in steel foundries.

Measures of Association

With attributes, that is, differences of kind, *measures of association* are used

to determine whether various incidents or events are associated more commonly than chance alone would allow. Percentages, proportions or raw values may be employed in different measures of association. With some tests like *Q* and *CC,* values range from 0 to 1 and thus parallel *r*; 0 reflecting *no* association and 1 reflecting *perfect* association. Most measures of association, however, yield values that must then be "read" on an appropriate table to determine whether the degree of association is statistically significant or not.

One measure of association is the simple *Q* test, applicable to simple dichotomous data, and two sets of attributes. If the data can be arranged as shown . . .

		Variable I.	
		—	+
Variable II.	—	a	b
	+	c	d

then Q equals

$$\S 10. \quad \frac{ad - bc}{ad + bc}$$

Better than Q, because exact tests of significance can be run, is chi-squared (χ^2). In the special form that is applicable to such a two-by-two or fourfold table, χ^2 equals . . .

$$\S 11. \quad \frac{(ad - bc)^2 \cdot (a + b + c + d)}{(a+b) \cdot (c+d) \cdot (a+c) \cdot (b+d)}$$

In this form, as with the example shown in figure 9, χ^2 serves merely as a test of significance. To measure the strength of the association it is possible to convert χ^2 into Φ^2 or the coefficient of contingency (*CC*).

Though measures of association have been designed for simple attributes of the present-absent, plus-minus, or small-medium-large sort, they are also applicable to fully quantitative data, breaking the distribution of the mean or median. While the correlation between tooth-size and jaw-size provides the most information, a simple test of significance will tell whether above-average teeth are associated with oversized jaws or vice versa.

Tests of Significance

Sampling error inevitably enters into every experiment or design. Simply by chance, one may sample more than the usual proportion of large-toothed boys and obtain a mean of 11 mm. for $\overline{M}_1$; purely by chance the obtained correlation between body size and tooth size may appear to be moderate. Attributes unrelated in fact may simulate association in a particular grouping. There is no getting away from the effects of chance, either by magic or by formula, but one can take the precaution of estimating the limits of the sampling error and then act accordingly.

For the mean, the sampling error, or standard error of the mean ($se_{\bar{x}}$) is simply and easily computed as . . .

$$\S 12. \quad \frac{\sigma}{\sqrt{N}}$$

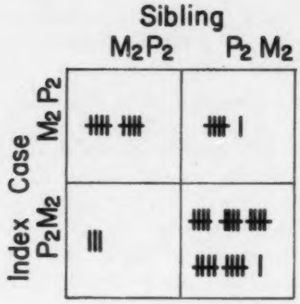
or, for small samples[3], certainly when $30 > N$ as . . .

$$\S 13. \quad \frac{\sigma}{\sqrt{N-1}}$$

Clearly $se_{\bar{x}}$ varies directly with σ and inversely with N: the more variable the sample, or the smaller the sample, the larger the standard error of the mean.

The use of $se_{\bar{x}}$ in tests of significance is more obvious if $se_{\bar{x}}$ is properly defined as *the standard deviation of obtained means about the true mean.*

[3] The symbol $>$ means "greater than" or "less than", depending on its position. $N > 30$ means that the sample is greater than 30. $30 > N$, on the other hand, means that the sample is less than 30.



Index Case \ Sibling	M_2P_2	P_2M_2
M_2P_2	(a) 10	(b) 6
P_2M_2	(c) 3	(d) 26

$$\chi^2 = \frac{(ad-bc)^2(a+b+c+d)}{(a+b)(c+d)(a+c)(b+d)} = \frac{(10\cdot26-6\cdot3)^2(10+6+3+26)}{(10+6)(3+26)(10+3)(6+26)} = 13.65$$

$$Q = \frac{ad-bc}{ad+bc} = \frac{10\cdot26-6\cdot3}{10\cdot26+6\cdot3} = 0.87$$

Fig. 9 Examples of two tests of association employed to determine whether siblings are similar in the sequence of M_2—P_2 formation. By the chi-squared test the tendency to cluster is significant at approximately the 0.001 level of confidence. The simple Q test suggests a high degree of association.

The limits $\pm 1\ se_{\bar{x}}$ include the extent either side of an obtained mean within which the true mean would be expected to fall 67% of the time: the $\pm 2\ se_{\bar{x}}$ limits represent the 95% limits and so on. Thus a difference as great as two standard errors would be expected, by chance alone, only 5% of the time (1 in 20).

It is therefore possible to employ the number of standard errors by which two means differ, as a test of significance, using the following formula when a sample is compared to the population . . .

§14. $$\frac{\bar{X}_{pop} - \bar{X}_{samp}}{se_{samp}}$$

and the following formula in comparing two samples, 1 and 2 . . .

§15. $$\frac{\bar{X}_1 - \bar{X}_2}{\sqrt{(se_1)^2 + (se_2)^2}}$$

The ratio in either case is called the *critical ratio*.

However, the critical ratio has long since been replaced by the more exact "*t*" test, properly called *Student's t* (it was first introduced by a statistician who signed himself "Student"). The *t* test, which should always be used when 30>N, makes use of the pooled variance (σ^2) from both samples, which is thus a better estimate of variance. Using the following formula for *t* . . .

§16. $$\frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(\frac{N_1\sigma_1^2 + N_2\sigma_2^2}{N_1+N_2-2}\right)\left(\frac{N_1+N_2}{N_1N_2}\right)}}$$

The result is then looked up (i.e. "read") on a table of *t* values in any major statistical text. One then determines at which *confidence level* (0.05, 0.02, 0.01, etc.) the difference is statistically significant.

Tests of significance for *r*, the pro-

duct-moment correlation, are similar in nature, having first computed the standard error of r from the formula . . .

$$\S 17. \quad 1 - \frac{r^2}{\sqrt{N}}$$

wherein se_r obviously decreases (1) as r increases or (2) as σ increases. Practically, if r equals twice its standard error, it is adjudged to be significant at the 5% level, as with the critical ratio. In comparing two correlations r_1 and r_2, the test of significance for the difference logically follows as . . .

$$\S 18. \quad \frac{r_1 - r_2}{\sqrt{(se_{r_1})^2 + (se_{r_2})^2}}$$

Tests of significance for measures of association, such as χ^2, are simple since the significance of a given value of χ^2 can be read directly on a table of χ^2. For example, a χ^2 of 3.6 is significant at the 5% level for a two-by-two (fourfold) table. Using the NPQ test[4], if two percentages differ by twice the standard error of the percentage, the difference is significant at the $p = 0.05$ level, and so on.

Tests of significance are simple and straightforward, providing the assumptions made in their use are fulfilled. For means, by way of example, it is a reasonable prerequisite that the distributions be normal and the variance of the two distributions nearly equal. In determining whether a correlation is significantly different from zero, one assumes that the entire range of values (and not just the extremes) are included. With χ^2 certain corrections must be made if the number in any box (or "cell") falls below 3.

The interpretation of a given value of t or χ^2 or p is similarly straightforward, if the user knows what he is doing, and what p (probability) values mean. In using a test of significance one determines whether the null hypothesis (assumption of no difference or a nil correlation) can be rejected, and at what level of confidence. This is an essentially conservative approach using betting odds. At a χ^2 of less than 3.6 (for a two-by-two table) one says that the data do not reject the null hypothesis. At 3.6 the data reject the null hypothesis at the 5% level of confidence. One can never argue that there is no difference or no correlation, merely that the null hypothesis can (or cannot) be rejected.

The confidence levels or p values similarly need an explanatory note. They are merely betting odds. A p of 0.05 means that the odds are only 1 in 20 that the difference could have come about by chance alone. A p of 0.01 refers to the 1 in 100 chance, and so on. What level of confidence to select is entirely up to the individual worker. Though the 0.05 level of confidence is used by many, he may prefer the 0.01 level. But he should be consistent thereafter; it is illogical to reject one difference because it fails to attain the 1% level, and then to accept another, significant only at the 5% level!

We should remember that p values are neither amulets nor holy medals. They do not protect the user against chance. A difference may attain the 1% level of significance and still be due to chance or it may not attain even the 5% level and be a real difference. Men cheerfully bet on horses or roulette wheels (where the chances may be as low as 1 in 1000) and still occasionally win.

[4] For a given sample, N, where P represents the percentage or proportion of an attribute a, and Q, (i.e., 100-P) represents the percentage or proportion of the contrasting attribute b, the se of the percentage is $\sqrt{\frac{PQ.}{N}}$

Much more common than the error of using p values incorrectly is the error of using the term "significance" incorrectly. A statistically significant difference is one of a magnitude that could be due to chance only once in X times. Significant is not necessarily equivalent to meaningful, or important, or useful. A correlation that is statistically significant may still be totally unimportant. A statistically significant difference may not be a useful difference.

Suggestions on Presentation

Statistical measures are working tools, designed to simplify, sharpen and protect numerical data. However, such measures are secondary, in any event, to the problem being investigated and should not be given excessive prominence. A research report too obviously freighted with symbols, formulae, explanations of tests and measures automatically betrays amateur status.

By now $\bar{X}$, σ, *se* and *CR* are familiar measures; they need not be specifically defined in a professional paper. A simple statement that a given difference is (or is not) significant at the 5% or 1% level ordinarily suffices. If a number of differences or correlations fail to attain the 5% level of significance, it is more economical to say so in the text, than to employ a special table for the purpose. And, if less familiar tests or measures are used, such as non-parametric tests, a literature citation, or at best a footnote, alerts the curious without encumbering the text.

A common error is the use of too many decimal points, the old ailment of specious accuracy. If measurements are taken in millimeters a mean rounded-off to the nearest tenth suffices: for measurements taken to the nearest degree, it is doubtful that fractions of a degree contribute to their utility. A χ^2 value of 3.6 is as meaningful as one of 3.6121. Similarly with correlation coefficients, two decimal places are surely enough.

Some workers desire to present all of their data, relevant or not, and useful or not. This habit is especially characteristic of the recent degree-winner who desires to print his thesis in all of its numerical glory. On the other hand, workers do drop into the unfortunate habit of citing undocumented findings, often referring to a still-unpublished manuscript. Both extremes are to be avoided, by the simple expedient of documenting all claims, but not tabulating data that remains unexplained in the text.

In the course of data analysis many more calculations will be made and statistical tests accomplished than need be detailed in a publication. For example, tests of skewness will be made before calculating *SD* and *se,* and r will usually be compared with η before r is accepted. Such busy work goes on behind the scenes. It is assumed that such tests have been accomplished, and a reference to them may be in order.

Properly used, statistical tests and measures are unobtrusive, present in the right places, but do not impede the reading. Similarly, the best statistical tabulations are simple, clear-cut and almost sparse. The author may have spent a day polishing one table into the most readable and compact form. If it appears deceptively simple, seemingly easy and natural, if the text runs along without pauses for statistical announcements, his efforts will have been a success.

Acknowledgments

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Physiologic Migration Of Anterior Teeth*

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INTRODUCTION AND REVIEW OF THE LITERATURE

The study of the physiologic movement of teeth is not new. G. V. Black ('08) has shown by actual measurements an average loss of about 1 cm. in the length of dental arch due to proximal wear at the contact areas of the teeth by the age of 40 years. He reasoned that since the teeth were still in contact the teeth must have moved toward the midline.

In 1925 Stein and Weinmann in their work on the mesial drift of teeth gave histologic evidence for this clinical observation. Microscopic examination of horizontal and mesiodistal sections of teeth and their supporting bone revealed a distinct structural pattern of the supporting bone. From this they deduced that teeth migrated mesially. Since then their findings have been accepted as indicating a physiological process and this has been substantiated by numerous investigators.

From studies of madder-fed pigs Brash ('28) came to the conclusion that there is a constant movement of all teeth in three planes of space. Not only do teeth move vertically but buccally and proximally as well. A review of the literature revealed that other studies had contributed indirect evidence to the question.

Bjork, ('47) employing cephalometric roentgenograms of a sample of 322 boys 12 years old and 281 conscripts between the ages of 22 and 23, found that the mean sagittal angle formed between the longitudinal axes of the upper and lower central incisors increased from 128.5° to 137.4°. This increase of 8.9° could only be explained by an uprighting or more vertical positioning of these teeth. Downs ('48) measured the same angle in 20 persons with normal occlusions with an age range of 12-17 years and found this angle to be 135.4°.

Noyes, Rushing, and Sims ('43) measured the same angle on 14 living people between the ages of 22-33 years and arrived at a mean figure of 129.3°. The measurement on 9 Indian skulls provided a mean of 131.4°. Both of these groups were composed of individuals with normal occlusion of the teeth. On 15 cases of Class II, Div. I malocclusion the angle was 132.2° and in 15 cases of Class III malocclusions it was 132.0°.

Schaeffer ('49) studied the behavior of the axes of human incisor teeth by means of serial cephalometric x-rays. His sample consisted of 47 series of lateral roentgenograms from the time the incisors were first in occlusion until 8 years later. He found that 18 individuals showed no change in the interincisal angle and in 21 individuals the interincisal angle increased. Eight individuals showed a decrease in the interincisal angle. A decrease in the angles denoted greater procumbency. It should be realized that the interincisal angle could change as a result of the

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axial change of either the upper or lower incisor as well as that of both. To determine where the change took place in any given case, Schaeffer was forced to relate the tooth axes to planes of reference. Thus, the upper incisor was related to the palatal plane, the lower to the mandibular plane. When he did this, he found that each of these angles may increase, decrease, or remain constant during growth, but the tendency once established was maintained. In other words, once an angle showed a decrease, increase, or stability, it continued to do so. Of the 13 possible combinations between the three angles all but 4 such combinations were found. This would tend to show an absence of a definite pattern of change in the inclination of the incisor teeth during growth.

Bjork ('47), Lande ('51), and Brodie ('53) on late growth changes in the face all revealed that the mandible became more prognathic with age. This tended to straighten the facial profile because the teeth and alveolar processes did not keep pace with the forward movement of the glabellar and chin regions. Such a differential growth pattern could quite conceivably influence the axial inclination of the incisors.

The present study was an attempt to determine whether a definite drift pattern of teeth existed in the labio-lingual direction. Because it was thought that single rooted teeth would yield a clearer picture, the study was limited to the upper and lower anterior teeth from cuspid to cuspid.

Because of the age range and distribution of the sample, the study is mainly concerned with changes that have taken place after growth has stopped.

Material

The material used in this study was derived from the files of the University of Illinois, Department of Oral Pathology, and from that of the Loyola University Dental School.

It consisted of 48 human teeth and their supporting tissues sectioned in a labio-lingual direction. The slides chosen were central sections which passed through the full length of the teeth from apex to incisal edge whenever possible. These 48 teeth were taken from 29 different cadavers. All were males.

Photographs of the maxilla and mandible in open and closed position and a brief history of the individual was available in most cases.

The age range of the sample was from 12 to 74 years with the majority of individuals falling between the ages of 30 and 55. The age of one individual is unknown. The photographs of 4 individuals were unobtainable.

The sections were stained with hematoxylin and eosin.

Method

The study consisted of the microscopic examination of each individual section and was entirely qualitative. Each slide was enlarged 30 X by means of a micro-projector on a large piece of paper. The outline of the tooth and the surrounding alveolar bone was traced, particular attention being paid to details indicating resorption and apposition of bone. By this method a clear picture of the drift or tipping tendencies of the tooth was ascertained in the majority of the sections.

A good example can be seen in the tracing of section #2b (Fig. 4). The lines present along the lingual alveolar wall and fundus can be diagnosed as resting lines and indicate where bone had been deposited. Their absence on the thin labial wall and the presence of scalloping indicate resorption. Thus it could be concluded that this tooth had undergone a labial drift and vertical eruption.

The use of resting lines in the alveolar bone as indication of previous movement of teeth is not new. The following definition of resting and reversal lines is taken from Weinmann and Sicher's book, "Bone and Bones".

> "A free and inactive surface of bone shows a peculiar staining reaction. The surface becomes increasingly basophilic and can be seen in a section stained with hematoxylin and eosin as a dark blue line, aplastic line, or limiting membrane. If, after some time new bone is laid down upon this surface, its layers are separated from the old bone by a dark blue cementing line, which is now called a resting line. It is straight or evenly curved.
>
> If bone tissue is resorbed and resorption ceases for a time, the resorbed surface shows the same reaction as previously described, that is, the appearance of an aplastic line. New bone apposed upon the resorbed surface is separated from the old by a cementing line which is called a reversal line. It is scalloped with its concavities corresponding to the former Howships lacunae. The convexities of the scalloped reversal line face the old bone."

Thus resting lines reveal two things: (1) that growth has occurred at a specific site and (2) that it has been intermittent.

The significance of bone growth and resorption at specific sites has been interpreted by Weinmann and Sicher as follows:

> "Growth of bone in circumscribed, exactly defined areas is the direct cause for tooth movement. The continuous growth potential of the cementum plays an important role in this process. The constant presence of a superficial layer of uncalcified cementoid renders the tooth relatively immune to resorption. Thus the pressure caused by growth (apposition) of bone on one alveolar wall is transmitted by the moving tooth to the opposite alveolar wall where it causes resorption."

However, the study told by resting lines is not a complete one because of the constant remodeling that occurs at all times. Thus some of the earlier resting lines have probably been removed when the bone underwent remodeling changes. Furthermore, the time interval represented by these lines is as yet undetermined. All one can say from existing resting lines is that the tooth had moved and in which direction but when this occurred is impossible to say.

Details of apposition and resorption occurring along the surface of the alveolar wall at the time of death was studied but is not reported in this paper for several reasons, a few of which bear explaining. There is a response in the periodental membrane that maintains the width of that structure within narrow limits under varying conditions of functional stress (Schour '56). The responsibility for this adjustment seems to lie in part with the cells of the middle zone of the membrane which have been shown to increase their mitotic activity with any increase of tension in the fibers (Reitan '51, Macapanpan '52). This leads to the formation of new fibroblasts which produce new fibers to adjust to the new position of the teeth, (Sicher '55). At the same time new bone is being formed on the alveolar wall and new cementum on the root surface. This activity occurs throughout life in the interest of maintaining adjustment of the teeth to changes in functional stresses (Gottlieb '43). With stimuli of short duration there is activity leading to minute absorptions and depositions but when the stimulus is of a continued nature, there is a more generalized involvement of the bone and cementum surfaces which can be read in the resting lines on the tension side.

Other factors tend to make difficult the determination of the direction of movement from an examination of the bone surface alone. When a tooth is subjected to a lateral stress, it does not move in a translatory manner but by tipping and the reaction of the alveolar bone is therefore scattered along both sides of the root. During this response

the osteoclasts frequently remove more bone than necessary to reduce pressure to normal and, in consequence, short periods of reparative apposition follow periods of resorption. However, osteoclastic activity is more easily discernible because of the presence of Howship's lacunae whereas the thin layers of newly deposited bone by osteoblastic activity are difficult to see owing to the thickness of the sections and the faint staining reaction.

When an apposition or resorption pattern could be ascertained in spite of these complicating factors, it was merely indicative of the state of this tooth at one instant of time while the cementing lines provided a diagram of phenomena over a much longer period of time prior to death.

Findings

(1) The study of the resting lines as revealed by microprojection showed a definite pattern of movement for all 48 teeth examined.

(2) The direction of movement was varied, 24 teeth showed some change in a lingual direction and of these 16 revealed a lingual tilt (Fig. 1), and 8 a lingual translatory drift (Fig. 2). There were 10 teeth which showed a change in the labial direction; three showing labial tilt (Fig. 3), and 7 a labial translatory drift (Fig. 4). Nineteen teeth showed vertical eruption (Fig. 5). Of these 10 had erupted in combination with a labial or lingual movement and 9 showed vertical eruption alone. Six teeth appeared entirely at rest (Fig. 6).

(3) When the reaction of upper teeth was compared to lower teeth, significant differences were apparent. Of the entire sample of 48 teeth 29 were uppers and 19 were lowers. The 29 upper teeth behaved as follows: 11 showed a lingual movement (6 tilt, 5 drift); 9 showed a labial movement (2 tilt, 7 drift); 12 showed vertical eruption and 3 were at rest. The 19 lower teeth showed a distinct difference in their behavior with 13 moving lingually (10 tilting and 3 drifting); 7 teeth showed vertical eruption; 3 were at rest and only 1 tooth had moved labially.

(4) When the sample was arranged in such a manner as to determine the effect of tooth position within the jaw, it was found that no definite pattern of behavior existed; central and lateral incisors as well as cuspids were shown to move in either a labial or lingual direction.

(5) Specimens from the same individual were studied next. There were 12 individuals from whom two or more teeth were derived. Of these the teeth behaved similarly in 5 individuals while in 7 they did not. The reasons for a difference of behavior of the teeth in these 7 individuals varied. Three individuals had at least two or more upper teeth that moved in opposite directions, one moving labially, the other lingually. The remaining 4 individuals showed a difference in movement between upper and lower teeth. In 3 of these 4 individuals the difference in movement was due to an opposite movement of upper and lower teeth (uppers labially, lowers lingually) while in the other individual the upper erupted, and the lower moved lingually. It it of interest to note that in two individuals (each with 2 specimens) both specimens were at rest even though in both cases one tooth was an upper and one a lower.

(6) The behavior of antagonistic teeth revealed a picture similar to the specimens from the same individual. A definite pattern of behavior could not be ascertained. Of the 8 sets of antagonists 5 sets showed a similar behavior while 3 sets behaved differently. The teeth that behaved differently did so by an opposite movement of the teeth, one moving labially while

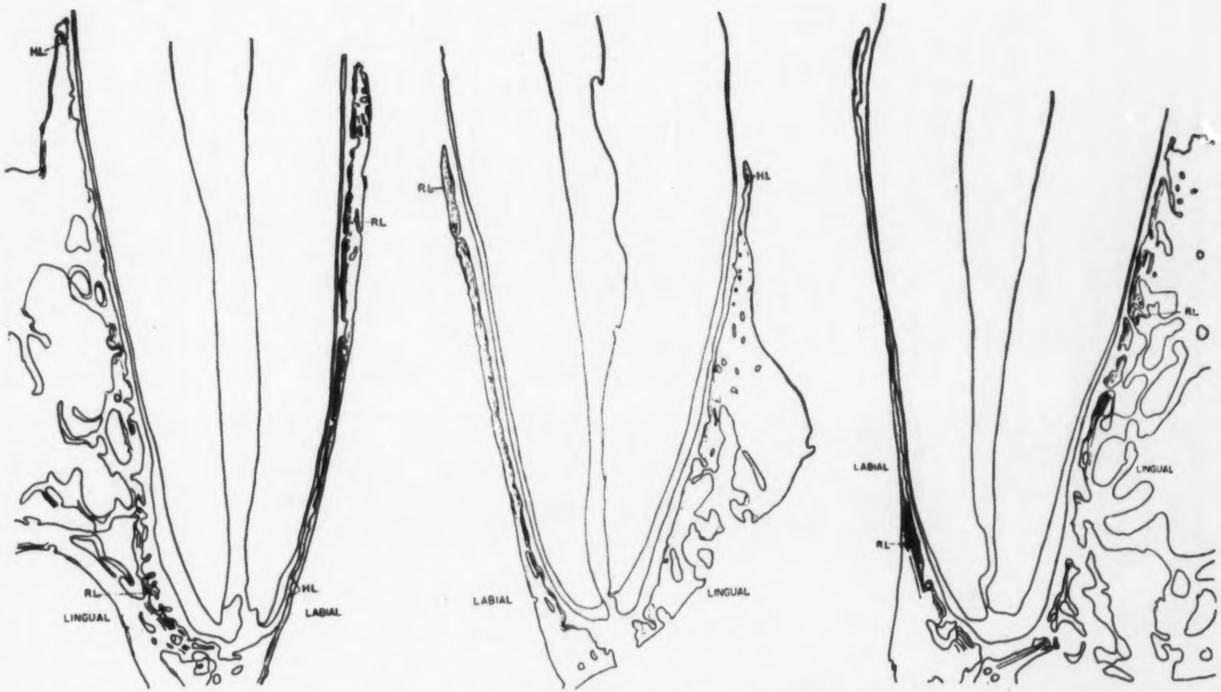

Fig. 1, left. Tracing of specimen No. 6, upper canine. Note resting lines (R.L.) in labial coronal half and lingual apical half of the alveolus, absence of such lines and the presence of Howship's lacunae (H.L.) in remainder of alveolus. Findings indicate a lingual tilt of tooth.
Fig. 2, middle. Specimen No. 7a, upper central. Note resting lines in labial alveolar wall, their absence, and presence of Howship's lacunae along lingual alveolar wall. Findings indicate a lingual drift. Fig. 3, right. Specimen No. 6b, upper canine. Note resting lines in labial apical third and lingual coronal half of alveolus and absence of such lines in remainder of alveolus. Findings indicate labial tilt of tooth.

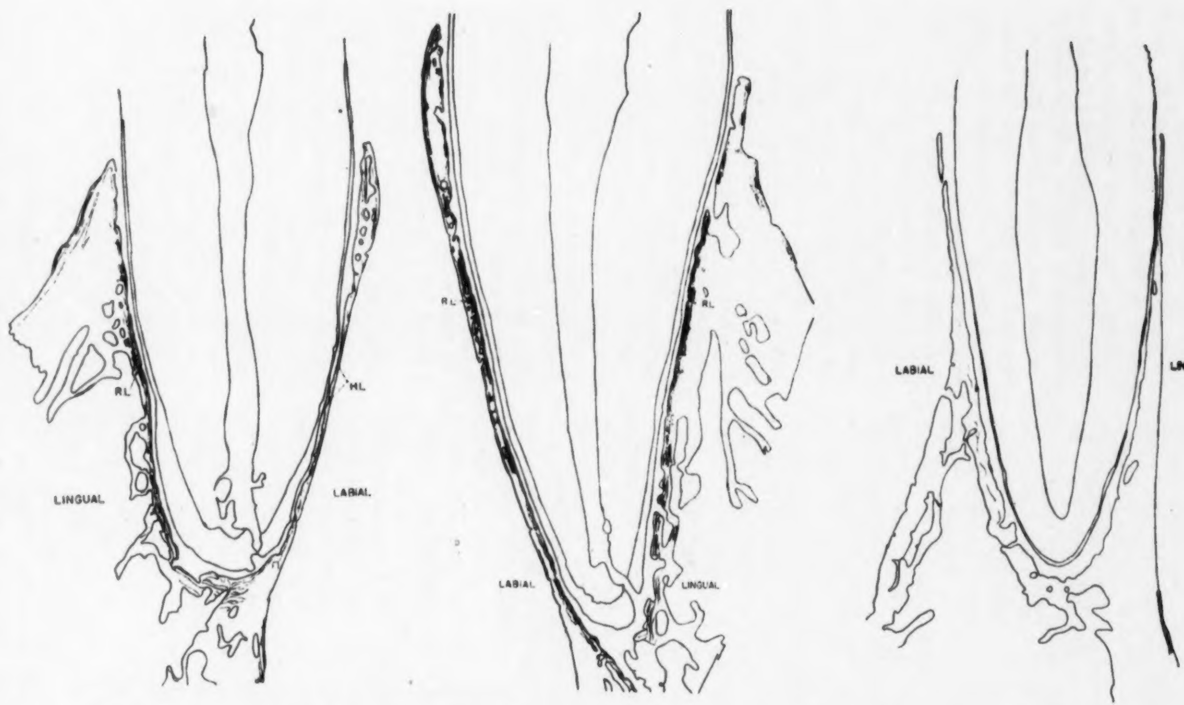

Fig. 4, left. Tracing of specimen No. 2b, upper lateral. Note resting lines (R.L.) along lingual alveolar wall, their absence, and presence of Howship's lacunae (H.L.) along labial alveolar wall. Findings indicate labial drift.
Fig. 5, center. Specimen No. 11b, upper canine. Note presence of resting lines along entire alveolar wall indicating vertical eruption.
Fig. 6, right. Specimen No. 1, lower central. Note absence of resting lines along alveolar wall indicating tooth is at rest.

the other moved lingually.

(7) The effect of attrition on the drift pattern once again revealed a lack of a definite tendency. Since the lower teeth showed a predominance of lingual movement, it was decided to study the behavior of attrition on the upper teeth alone. Of the 9 upper teeth from jaws showing only a slight degree of attrition 5 showed lingual movement (2 tilt and 3 drift), 2 showed a labial movement (both drift), 3 showed eruptive movement and 1 was at rest. Of the 13 teeth from dentitions with a moderate degree of attrition, 4 showed lingual movement (3 tilt, 1 drift), 6 labial movement (1 tilt, 5 drift), 6 an eruptive movement and 1 was at rest. There were only two dentitions with a severe degree of attrition; 1 showed a lingual drift and one vertical eruption.

(8) When the effect of alveolar bone loss on the drift pattern of the teeth was studied, there seemed to be a direct correlation between bone loss and labial movement. When the entire sample was studied, this correlation was not as clear as when the upper teeth were studied alone. Of the 7 upper teeth which had suffered a slight degree of alveolar bone loss, 5 had moved lingually, 1 had moved labially, and 3 had undergone vertical eruption. There were 11 upper teeth which showed moderate bone loss. Of these 2 had moved lingually, 3 labially, 5 showed eruption and 3 were at rest. Of the 11 upper teeth that had suffered severe bone loss, 4 moved lingually, 5 labially, and 4 showed eruption. Here it could be seen that the number of teeth showing labial movement increased as the bone loss increased. Only 1 out of 7 teeth moved labially when the bone loss was slight; when it was moderate, 3 out of 11 teeth moved labially, and when it was severe, 5 out of 11 teeth moved labially.

(9) The degree of mutilation (loss of teeth) seemed to have a correlation on the drift tendencies of the teeth studied. When the teeth were arranged in order of increased mutilation of their respective jaws, the tendency for labial movement of teeth seemed to increase. Lingual movement did not appear to be correlated with the degree of mutilation. Once again the upper teeth were examined alone, first in the order of increasing mutilation of the upper jaw and then in the order of increasing mutilation of the lower jaw. This was done to see whether the movement of the upper teeth was more dependent on the integrity of the maxillary dental arch or on the integrity of the lower arch which supports it. In both cases the labial movement of the upper teeth was directly correlated with the degree of mutilation while the lingual movement was inversely correlated.

Of the entire sample only two teeth were taken from jaws which contained a full complement of teeth. They were specimen #12, a lower cuspid taken from Jaw A 7, and specimen #4, an upper central incisor taken from Jaw K T. Specimen #4 showed vertical eruption while specimen #12 exhibited a labial tilt plus eruption.

(10) Finally, the sample was examined to see if any racial tendencies existed. Of the 29 individuals comprising this sample 10 were Caucasian and 5 were Negroid. Unfortunately the racial status of the remaining 14 individuals was unobtainable. Fourteen Caucasion teeth were studied. Of these 6 showed lingual tilt; 2 showed labial drift; 4 showed eruption and 4 were at rest. Of the 8 Negroid teeth studied 3 showed lingual movement; 3 showed labial tilt; 3 showed eruption and 2 were at rest.

Discussion

The most consistent finding was the lingual movement of the lower teeth.

The upper teeth moved labially or lingually with equal frequency. This would tend to confirm Bjork's findings of an increase in the interincisal angle with age. Schaeffer's work also demonstrated that of the 46 individuals studied serially, 21 had an increased interincisal angle, 17 remained constant and only 8 decreased. This again would seem to point to a lingual movement of either the upper or lower incisors or both since such lingual movement would lead to an increase of the angle.

However, the findings in this study must be evaluated in the light of the sample used. If the teeth studied here had all been derived from jaws possessing unmutilated dentitions, the findings could be considered truly representative of normal physiologic behavior. However, only 2 individuals of the 29 studied had a full complement of teeth; these were jaws A 7 and K T. Unfortunately, only 1 tooth from each jaw had been sectioned in a labio-lingual direction. Specimen #12, taken from jaw A 7, was a lower left cuspid. This tooth showed a labial tilt, plus eruption. This was the only lower tooth to show a labial movement. Specimen #4, taken from jaw K T, was an upper right central incisor and showed vertical eruption. The remaining lower teeth all came from lower arches with one or more teeth missing. Of the 18 remaining lower teeth 13 showed a lingual movement; 3 were at rest and 2 showed vertical eruption, (5 others showed eruption combined with lingual movement.)

These findings furnished histological evidence for the clinical observation that the lower arch collapses lingually with the loss of its continuity. A word of explanation is due here: in the normal dentition we find that the upper dental arch overhangs the lower dental arch by one half cusp buccally. Thus the lower arch is considered a "contained" arch lying wholly within the upper. When we consider the effect of occlusion upon these arches, we note a tendency for the upper teeth to move buccally while the lower teeth are forced lingually. Thus the lower teeth are being forced into an arc of a smaller radius making the continuity of this arch an extremely important factor in resisting the tendency for lingual movement. With a loss of continuity (due to loss of one or more dental units) a lingual collapse of the lower teeth generally takes place. When the reaction of such a collapse on the lower anterior teeth is considered, the situation is further aggravated by the anatomy of the maxillary incisors and cuspid teeth. Their oblique lingual surface will guide the lower teeth lingually and upward. The reaction of the upper teeth to this collapse is dependent upon a multiple of factors. The deep overbite may be due entirely to movement of the lower teeth. In this case, the upper teeth will be at rest. On the other hand, since the equilibrium of the denture has been disturbed by a collapse of the lower arch, it is possible that the upper teeth will, in turn, tilt lingually until a new equilibrium has been established. A third alternative is that, as the lower teeth ride up the lingual surface of the upper teeth, these in turn will be tilted labially due to a new vector of occlusal force. As is so often true with biologic reactions, there is no single invariable reaction. All probably occur, singly or in combinations, in different individuals. Examination of the behavior of the upper teeth in this sample in which all except specimen #4 were associated with a mutilated lower arch seemed to bear out the above contention. Of the 28 remaining upper teeth, 11 showed lingual movement, 9 labial movement, 5 vertical eruption, 6 showed eruption combined with a labial or lingual

movement and 3 were at rest. Further evidence was found in the examination of the 8 sets of antagonistic teeth. Six of the lower teeth showed a lingual movement, and 2 were at rest. In the cases in which the 2 lower teeth were at rest, both upper teeth were also at rest. In the jaws in which 6 lower teeth showed lingual movement, 3 upper teeth also showed lingual movement while 3 upper teeth showed a labial movement, once again illustrating the variability of movement of the upper anterior teeth.

The behavior of resting teeth is of interest. In two cases where there was more than one specimen from a jaw and one of these teeth was at rest, the other was also at rest. More significant was the fact that in both cases one tooth was an upper and one a lower. The explanation for this might be that a state of equilibrium had been reached in the individual denture that had persisted for quite some time. Both sets of resting teeth were from severely mutilated jaws although in one individual the missing teeth had been replaced by fixed bridges; thus the resting picture might have been caused by that restoration.

When the sample was arranged according to an increase in alveolar bone loss, there appeared to be a direct correlation between labial movement and the increase in alveolar bone loss. Because the lower teeth exhibited an almost uniform lingual movement, a study was made of the upper teeth alone. This study revealed that as the alveolar bone loss increased, there was an increase in the number of teeth exhibiting labial movement. Of the 7 teeth showing slight alveolar bone loss, only 1 showed such labial movement. Of the 11 teeth exhibiting moderate alveolar bone loss, 3 showed labial movement. Five of the 11 teeth with severe bone loss exhibited labial movement. A possible explanation for this may be that as the supporting bone loss increases, the teeth are less resistant to occlusal forces, and therefore are more easily forced labially.

A very similar pattern was shown when the teeth were arranged in order of increasing mutilation. Once again, the lower teeth were excluded in the hope that the uppers alone would show a clearer picture. This time the upper teeth were arranged according to increased mutilation in the upper arch, and then according to increased mutilation in the lower arch. Both showed an increased labial movement with an increase in mutilation of the arch.

The examination of the micro-projection tracings reveals a wide range in the number of the resting lines designating the previous positions of the teeth. This gives the impression that one specimen has undergone considerable movement while another has moved only slightly. It must be remembered, however, that bone is a dynamic tissue, undergoing constant remodeling and with this remodeling there is a loss of resting lines. Thus their appearance at the time of sectioning does not give a quantitative answer to such questions as the amount of movement that has occurred or when it had occurred.

Summary and Conclusions

(1) The present study was based on a histologic examination of 48 anterior teeth and their supporting tissues sectioned in a labio-lingual direction.

(2) A study of the resting lines in the alveolar bone by means of the micro-projection technic allowed the reconstruction of a concise and quite accurate picture of the movement of teeth.

(3) The general tendency of a lingual movement of lower teeth was apparent in the sample studied. At the same time, the upper teeth showed a

tendency to move either labially or lingually.

(4) Resting teeth from the same individual seemed to exhibit a strong tendency to behave similarly. This probably reflects a state of equilibrium that has been reached in the individual's denture.

(5) The increase in alveolar bone loss of upper teeth seemed to promote a labial movement of the upper teeth.

(6) The mutilation of the arches (upper and lower) had a direct correlation with the labial movement of the upper teeth.

(7) The present study, while conclusive as to the difference in behavior of upper and lower teeth, is hampered by the nature of the sample. To see whether these differences would be equally apparent in a sample taken from complete dentitions is of interest and requires further study.

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Past And Present Concepts Of*
Anchorage Preparation

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Anchorage preparation to many is quite a stranger. Most of us are aware of its existence. Some are acquainted with its origin. Others have seen its accomplishments. Few orthodontists are actually using it. Just what is it? The term anchorage, as used in orthodontics, refers to a source which can resist the reactions of orthodontic forces.

A discussion of the development of present day concepts of anchorage involves a review of the search through the years for the ideal appliance — one which permits force application from a perfect source. A review of the literature is a fascinating subject. Time will permit only a brief mention of a few of the background contributors. For those of you who are interested there are several well-written articles and a great deal of information in the early books and writings of Angle[1], Case[2], Guilford[3], and others. Brodie[4] gave a fine review of this subject at the last biennial meeting of this society.

It is interesting to note that Pierre Fauchard in 1728 described the first arch which was a flat perforated ribbon. This arch, or "bandeau", was ligated through the perforations to the teeth. A reciprocal series of forces was set up pitting against each other each of the teeth involved. This made use of the principle of reciprocal anchorage. A century later, in 1841, Schangé devised an arch soldered to a skeleton crib which afforded positive purchase on the teeth. He also developed the first clamp band.

Occipital anchorage was introduced by Kingsley in 1866. There are many who claim that the ultimate in anchorage was developed years ago through the use of these occipital or extraoral forces.

The early bands were problems because of tooth decay. With the advent of the cemented band, orthodontia became a more exact science, and credit for the cemented bands, according to Angle[1], goes to MacGill in 1871. Dr. Angle, in 1886, wrote about the use of small delicate tubes and shortly thereafter he described in the literature the "E" arch, or expansion arch. The jackscrew had become quite popular and was used for many years.

In 1898 Calvin Case[2] advocated the use of reciprocal elastics to effect movement between individual teeth in opposite arches. However, it remained for Baker, with the use of Angle's "E" arch, to apply those elastics in the correction of Class II irregularities. In his seventh edition, Dr. Angle called intermaxillary anchorage the "ideal force". The reciprocal activity of each end of the rubber band, he claimed, provided the best anchorage for the correction of the Class II condition and the creation of normal occlusion.

Prior to the use of intermaxillary forces occipital anchorage had become quite popular. The sequence of usage of many mechanisms is somewhat obscure. In reviewing the several sources[1 2 3 4 5 6] of information about the development of these devices it was apparent that at the turn of the century and shortly thereafter, many men, working independently, seemed to be

*Read before the Midwestern Component of the Angle Society, January, 1957.

trying feverishly to develop the ultimate in orthodontic appliances.

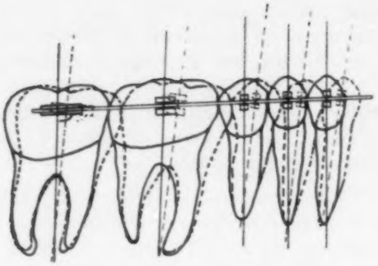
The demands on anchorage became greater as more refinements in force control were developed. Spring levers working from the round arch and anterior bands with ligatures tied to spurs improved the technical manipulation of the individual dental units. Orthodontic texts were written and anchorage was classified into several categories—simple, compound, stationary, etc. It was decided that the best anchorage in the mouth was one which permitted only the resistance teeth or anchor teeth to be moved bodily. This was called stationary anchorage.

As the search for better anchorage developed, it became apparent that more control was required over the individual dental units. As a result, Angle, expanding on this thesis, developed the pin and tube appliance and then the ribbon arch to afford greater mechanical advantages. This was an aftermath of the use of intermaxillary force which required all of the teeth to be resistance factors or anchorage units in the arches. The edgewise appliance, as first described by Angle in 1928[7], was designated as the "latest and best" of the time. Even today the many possibilities afforded by it are just being realized. However, the pendulum swings and modern orthodontics is again applying some of the so-called simple anchorage devices very successfully in the treatment of many types of malocclusion.

We have become aware of the many problems that have developed because of anchorage inadequacy and many men have advised the use of auxiliaries such as muscular, tissue borne and occipital supports. An excellent analysis of the anchorage problem was published recently by Earle Renfroe[8]. He analyzed the resistance factors of all the known sources of anchorage — the teeth, bone, musculature and extraoral areas. In this article he stresses the application of some of the early principles advocated by Angle, Case, Dewey, McCoy, and others. He analyzed the efficiency of several auxiliaries as anchorage mechanisms.

However, we will sidetrack the discussion of these devices and pursue the development of the edgewise mechanism and the anchorage possibilities afforded by it. The force exerted by the edgewise mechanism, as it was originally intended by Dr. Angle, involved the principle of short reciprocal levers directed from each tooth through the arch to its adjacent tooth on either side. The principle of bracket purchase involved fixation of an .022 x .028 archwire into a bracket designed to receive this wire. The first treatment results reported cephalometrically through the use of edgewise appliances were made in 1938 by Brodie, Downs, Goldstein, and Myer[9]. One of the conclusions concerning the effect on the mandibular arch or the anchorage unit in the Class II, Division 1 cases was that considerable mesial movement of the mandibular buccal segments occurred.

In order to assess properly the meaning of such a conclusion one must consider the problems associated with the use of the edgewise arch. There is clearance or leeway between the archwire and bracket. Because of the jiggling between the wire and the bracket the teeth will tip if a mesial force, such as a tieback ligature, is used (Fig. 1). This is especially true when the use of intermaxillary Class II activity is applied (Fig. 2). Here the teeth not only tip, but due to the directional pull of the elastics the posterior teeth are elevated in the mandibular arch. This creates problems, such as tipping of the occlusal plane which, subsequent to retention, very often allows a return



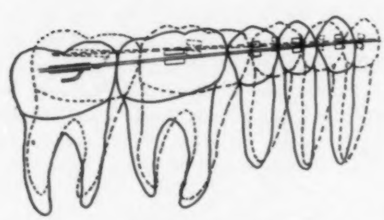


Fig. 1, above. Mesial tipping which occurs when a straight arch is tied back.
Fig. 2, below. Mesial tipping and elevation of lower molars when Class II mechanics are applied.

of overbite. It was thought that reinforcing the edgewise mechanism with a soldered lingual arch or stabilizing plate would help. This was done to increase the anchorage potential. These auxiliaries had certain advantages and were found to serve nicely in meeting specific demands. For example, to reinforce the arch to permit uprighting of tipped cuspids or a single unerupted tooth, a removable or soldered lingual auxiliary arch is quite effective. It is also useful in some cases in which the entire arch is pitted against one or two teeth. However, such auxiliaries will not afford effective resistance to the tipping action on the occlusal plane of the intermaxillary pull. Many of us have found ourselves removing lingual arches after they have embedded themselves deeply into the lingual mucosa.

Tweed, perplexed with the problems that he found through the use of the edgewise arch in his hands, decided that the only way to get a satisfactory anchorage was to prepare it. Originally, he attempted to do this by moving the anchorage unit into a disto-angular inclination (Fig. 3). He evolved his well-known Tweed philosophy of placing the mandibular incisors over basal bone and repositioning the remaining teeth in such fashion that they not only were in harmony with the anterior teeth, but also at such angular relationship to the pull of intermaxillary force as to resist displacement. His mechanics of doing this are well known.

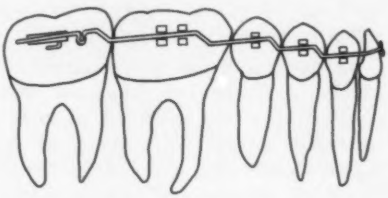


Fig. 3 Diagram of a prepared arch.

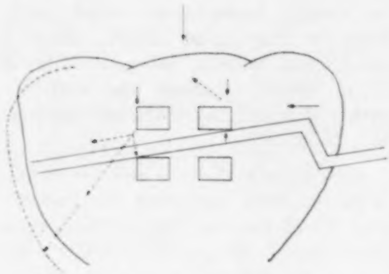
When it was first presented, the term "anchorage preparation" did not seem to be in harmony with basic biological and physiological evidence. Clinical usage, however, has justified its application. It has been used quite successfully for some time.

What makes a prepared anchorage unit different from a conventional arch with a heavy wire? An analysis of the forces is interesting. If it be true that a prepared unit has a greater tendency to resist displacement, there must be a physiological explanation that can be accepted. It is probably agreed that biological resistance to bodily movement is greater than the resistance to a tipping force. There must, therefore, be greater purchase of each tooth along the root surface as it is pulled mesially in a prepared unit in which it is difficult to tip teeth, as opposed to the simple tipping action of the teeth

against the alveolar crest and the apical bone area. Since the tooth and the periodontal structures are designed to resist the forces of occlusion which are in a downward direction, any vector of orthodontic force in that direction is undoubtedly going to resist movement to a greater degree than a force exerted in any other direction. Such is the case of the so-called "prepared" tooth. The combined action of the bodily resistance of each tooth to movement and the absorption of a certain degree of the intermaxillary force in an apical direction is offered as a possible explanation of the efficiency of the "prepared" unit.

The present term given to the application of anchorage preparation is "dynamic anchorage". The mechanical requirements insist that the tip-back bends in the anchor arch be periodically activated slightly to exert active purchase against the brackets. It is also necessary to religate the tie-backs to place tension in the archwire. The principle is to neutralize the small amount of mesial tipping of the tooth due to "play" and to keep the tooth in such position that the resistance to the intermaxillary force tends to continuously keep the mesial movement of the anchor teeth in a bodily direction. The anchorage arch must always have active second-order bends to exert purchase on each tooth when elastic pull is exerted. Without the second-order bends in the anchor arch, the pull of the elastic is transferred to the archwire directly on the anchor molar tooth and indirectly through contact pressure to the remaining teeth in the buccal segments and again directly to the anterior teeth. The use of the teeth in the buccal segments as stationary units is lost when this elastic pull is not transferred equally or at least to a greater degree among several of the teeth rather than the molar tooth with its sheath. Second-order bends, tied-back to the molar sheath, offer a mechanical pressure on each of these teeth directly through the archwire rather than indirectly through the contact point.

How is the anchorage arch prepared? This has been described by Tweed[10] and is well-known. The maxillary arch has a heavy .022 x .028 archwire reinforced by occipital anchorage during which time Class III elastics are worn. When the headgear is not worn, very light elastics are placed. Cephalometric records have shown that there is very little mesial migration of the maxillary arch during this time. The mandibular archwire is reduced in size. The Class III force may be applied directly to the mandibular archwire in the canine area or directly to the molars by means of sliding yokes. During the process of preparing the anchorage unit, occlusion, which has often been referred to as an antagonist to tooth movement, can be made to aid the movement of teeth through what Tweed calls "racheting" action of the tooth on the archwire (Fig. 4). This may be explained as the same type of activity that occurs when the teeth are deflected forward during occlusion in the creation of the anterior component of force. Due to the inclination of the teeth and the direction of the path of closure, one of the factors influencing the anterior component of force, as explained by several authorities, [6 11 12] is a forward vector that is created when the teeth occlude. During the anchorage preparation step, occlusion, as it strikes the tooth, transfers this force through the bracket to the archwire. A disto-gingival vector of force is produced as the bracket strikes the archwire. The buccal teeth are guided down the inclination of the wire by the distal intermaxillary force directed against the teeth aided by the distal "racheting" effect of occlusion.



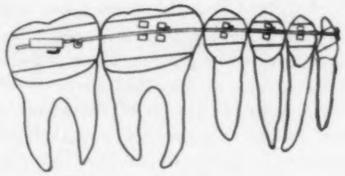


Fig. 4, above. Diagram of the forces acting upon a tooth undergoing the process of anchorage preparation.
Fig. 5, below. Diagram of a prepared mandibular arch using inclined brackets and a straight archwire.

There is another method by which anchorage may be prepared (Fig. 5). Considerable success has been reported through the use of inclined brackets in the buccal segments as advocated by Holdaway. The essential difference between the two methods is that with the application of Class II force the archwire will slide through the brackets when a straight wire is used. It is the contention of those who subscribe to this method that, although some mesial tipping occurs when the Class II mechanics are applied, if properly preceded by use of Class III mechanics from the placement of the first archwire, the teeth will tip no farther than the amount of play between archwire and bracket, and then frictional resistance will prevent further tipping. The brackets are deliberately angulated to compensate for this tipping. The straight wire loses the advantage of direct purchase between the archwire and each tooth in the buccal segments; however, by simplifying the technique of the anchorage preparation much time and effort are saved.

Considerable controversy has existed during the past several years concerning the necessity for anchorage preparation. There are those who subscribe to the principle of preparing mandibular anchorage in all cases in which Class II mechanics are to be applied. There are others who are yet to be convinced of the necessity for such procedure except perhaps in the most unusual circumstances, and even then they question the creation of any beneficial effect. There are many among us who at some time or other have made a half-hearted attempt at "setting up anchorage" and, during the course of treatment, have become alarmed at the severity of the overjet and perhaps the open bite that had begun to develop. We quickly and silently condemned ourselves for permitting such a "mess" to develop. At that time we were thoroughly convinced that anchorage preparation was not advisable and such unscientific procedures were not to be condoned. Why get involved in a back and forth movement in the mandible when headgear and mild Class II mechanics are all that are needed to correct the average Class I condition?

One concession must be made by even the most skeptical among us; that is, many cases have been demonstrated clinically with models, headplates and photographs wherein dramatic change has been induced by mechanics involving major anchorage preparation in the mandibular arch.

There have been several recent studies on consecutively treated cases taken from the office of Dr. Charles Tweed in which anchorage preparation was used on all severe Class II, Division 1 and bimaxillary protrusion cases. The results have demonstrated that spectacular changes have occurred.

It is not the intent of this paper to promote the objectives of Dr. Tweed nor to agree with him in what necessarily should be the goal of treatment in our orthodontic service, However, one cannot but be greatly impressed with the extent and frequency with which favorable changes occur in "growth response" and with the improvement in denture base relationships in his cases. In a discussion of apical base changes Holdaway[13] gives his explanation of the favorable facial and denture responses in Tweed's cases. "First, Tweed begins all such cases with Class III elastic pull, tipping back the lower teeth to establish what he terms dynamic or 'toe-hold' anchorage of the lower arch in order that these teeth will later resist the displacing action of the vigorous Class II elastic pull. The immediate effect is to tip the occlusal plane downward at the distal side due to the downward and forward pull of the Class III elastics. These lower positioned upper molars tend to become the fulcrum point around which the mandible rocks when it is later held forward by Class II elastics.

"Second, lower molar teeth that are well tipped back resist the usual tendency to elongate, a tendency so noticeable when Class II elastics are applied to a lower arch without first tipping them back . . . therefore, we have a situation in which the upper posterior teeth are encouraged downward early in treatment before they are appreciably tipped back; and the lower anchor units, if properly prepared, are encouraged to resist the elongating effect (Fig. 6).

"Third, Tweed's treatment is vigorous. Approximately one-third of his total treatment time is devoted to the preparation of lower anchorage, and still his overall treatment time averages about fifteen months for extraction cases and thirteen months for non-extraction cases."

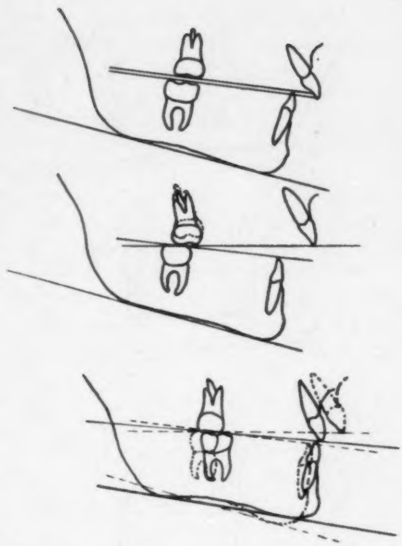


Fig. 6 Illustrations of Holdaway's explanation of changes in the occlusal planes during Tweed treatment. Top, upper and lower occlusal planes before treatment. Middle, upper and lower occlusal planes after anchorage preparation. Bottom, after Class II mechanics are applied. Dotted line represents position of teeth at the end of anchorage preparation.

The recent study by Stoner, Lindquist, Hanes, Vorhies, Hapak, and Haynes[14] did not follow Holdaway's contention that this response occurred in most cases so treated. Assuming anchorage preparation was used as advocated, there was found that in addition to the above-described changes, the mandible would follow a desirable downward and forward growth or positional change during which time there was a minimal mesial displacement of the denture on the ridge. However, the lower molars elevated somewhat, and the lower incisors depressed slightly (Fig. 7).

Also found were cases with no forward change at all in the mandibular

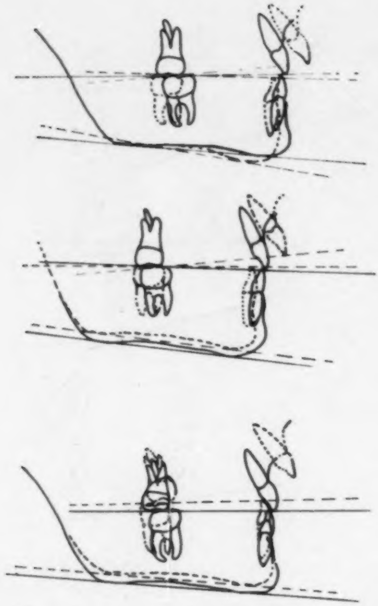


Fig. 7 Three types of responses when Class II mechanics are applied after anchorage preparation.

arch. The entire maxillary arch descended an amount equivalent to the vertical growth in the mandibular arch.

There were other cases (not shown diagrammatically) in which the bite opened with the mandible moving posteriorly following the same type of tooth movement as shown in the third diagram in Figure 7.

Still other cases showed few mandibular changes, but maxillary changes were demonstrated in a posterior direction. Point A moved posteriorly as much as 7.5 mm. when the cephalometric radiograph was superimposed on SN at N and 6.0 mm. when superimposed on SN at S (Figs. 8, 9, and 10).

These changes did not necessarily correlate. The outstanding accomplishment was that, according to Tweed's standards and many others, facial esthetics were improved during the course of treatment and the anterior horizontal differences between points A and B were nearly always reduced considerably. The conclusions implied that in some cases anchorage prepara-

Fig. 8, left. Case M.G. Superposed on SN at N. This case was treated using a prepared mandibular arch. Note excellent growth in the mandible, change in position of point A, and bodily retraction of the maxillary incisor. Fig. 9, middle. Case J.H. Superposed on SN at N. A prepared mandibular arch. Mandibular growth good but not as favorable as Fig. 8. Maxillary changes are favorable. Fig. 10, right. Case J. T. Superposed on SN at N. Another prepared lower arch. Mandibular growth not favorable but dramatic change in the maxillary arch occurred.

tion permitted a directional growth response in the mandible which might not have occurred to as great a degree unless the lower incisors were lingually positioned to permit such change. In the maxillary area a similar but opposite directional change occurred (restraint) which was manifested by a distal recontouring of a portion of the maxilla, especially in the anterior apical base area.

We recognize that facial change, as has been pointed out by Bjork[15], Downs[16], and Lande[17] is naturally changing through the years from a convex to a flatter profile. Orthodontically we are trying to aid nature achieve the type of change that would normally occur to a degree. It is possible in many instances to recognize and anticipate the degree of change that will occur within the growth potential of the individual case. Careful thought must be given to the selection of the proper type of mechanics and treatment. In so doing, the decision to utilize prepared anchorage, as opposed to natural, reinforced or extraoral anchorage, must be made with the knowledge of the possibilities and limitations of the anchorage required.

It must be understood that favorable growth responses have been demonstrated when many different technical procedures have been used. A concept of anchorage must depend on an evaluation of the inherent growth potential of any given case and an acceptance of objectives to be attained in treatment. In many cases anchorage preparation will only be necessary if certain goals or objectives of treatment are to be achieved. If the retraction of the mandibular incisors is considered necessary, it offers an effective means to retract these teeth. If maximum reduction in denture base discrepancies is desired, retracting the mandibular incisors has been found to permit the mandible to come forward or give additional room for bodily retraction of the maxillary incisors or some combination of both. There are, however, limitations to all technical procedures. Figure 11 shows three different cases with similar skeletal patterns. All were within an active growth period and were treated differently. The first was treated by means of a bow-type removable headgear only. The second was treated by extraction of upper first bicuspids and light Class II elastics with a headgear on the maxillary arch. The third case was treated with anchorage preparation in the mandibular arch. We believe the treatment in each of these cases was quite effective (Fig. 12). The benefits derived in the first case are clearly demonstrated. In the second case the severe A-B relationship coupled with the steep mandibular plane, indicating poor growth potential, limits the application of a prepared anchorage in the correction of this Class II relationship. The third case demonstrates how, with a steep mandibular plane, effective treatment can be accomplished with considerable desirable change. The changes in the first case could have been further improved if the case had been treated with a prepared mandibular arch after this step.

The use of prepared mandibular anchorage has some decided advantages in the correction of certain Class II discrepancies and bimaxillary protrusion cases. For instance, it reduces distortion of the occlusal plane. It is very effective in minimizing overbite problems; it permits control in positioning of the lower anterior teeth during treatment and minimizes total arch displacement. It effectively offers additional anchorage for bodily retraction of the maxillary incisors. It also seems to be followed in some cases with mandibular growth and in others offers resistance factors which permit the maxillary

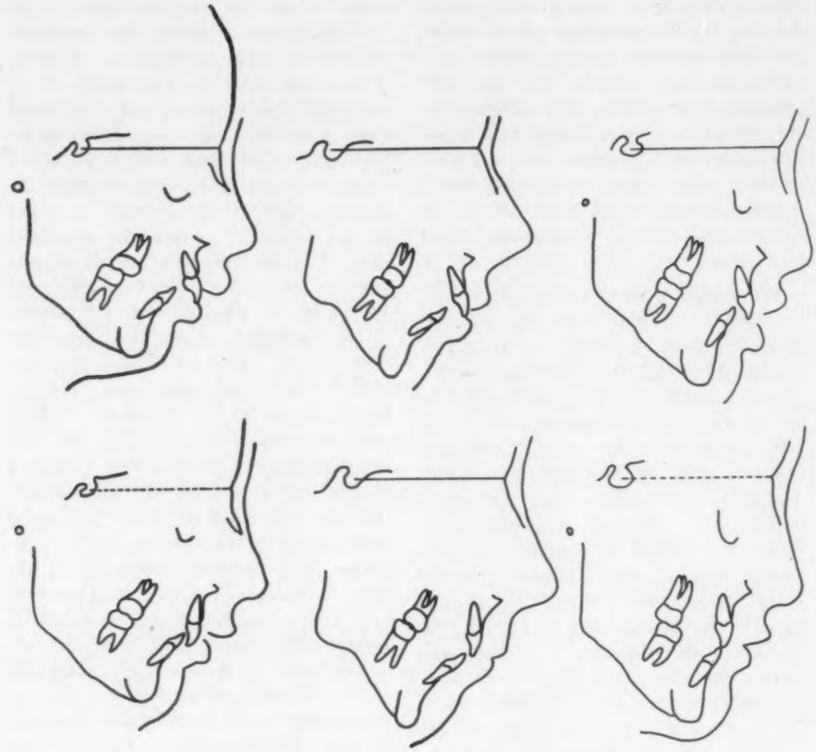


Fig. 11, above. Three cases with severe patterns before treatment.
Fig. 12, below. The same cases in Fig. 11 after treatment.

base to change. On the negative side—it is a complicated technique. It is unnecessary in mild arch length cases in which there is little A-B discrepancy. In steep mandibular plane cases combined with very severe A-B denture relationship in which favorable mandibular growth is probably unobtainable, the desired improvement may not be forthcoming.

We have dwelled a great deal on anchorage preparation. However, it is not the final answer nor is such procedure the only method of treatment in many of these cases. After all, many cases do not exhibit A-B relationships that need great change. Nor does it necessarily follow that the arch length requirements of a given case demand the utmost conservation of anchorage. At this time we will discuss the present day application of extraoral anchorage. Much has been written about the effect of occipital and cervical forces on growth and development during the treatment in the mixed dentition. The present day application of occipital anchorage as advocated by Kloehn[18], Nelson[19], and others [20 21 22] has demonstrated the positive effect of such force on the development of the dentition. There is a decided influence on the position of the teeth and its denture base. It has been demonstrated

cephalometrically that there are limitations to its use depending on the initial pattern, the severity of the malocclusion, and the unpredictable factor of growth response. The term "growth response" is used loosely since its effect in these cases as analyzed recently by Graber[23] has not been conclusively demonstrated to be valid.

There are many refinements of application of this force which have specific advantages. Occipital force may be directed to the archwire by a hook in the canine area. The direction of pull can be controlled to exert distal traction along the line of the arch or even in an upward direction. The disadvantage of the downward pull of cervical anchorage when directed to the anterior section of the maxillary canine area results in an elongation of the anterior teeth and deep overbite problems at the termination of treatment. The intraoral bow transferring pressure to the arch in the molar area has the advantage of avoiding this problem but has the disadvantage of being unable to permit directional control of pressure on the anterior teeth as effected by the so-called "Northwest" or "Steiner" headgear.

In addition to being used as an active force in the movement of teeth or as a device in the control of growth, occipital anchorage has many other anchorage possibilities in modern orthodontics. There is the currently popular method of reinforcing the existing anchorage by extraoral means. The headgear is used in the mandibular arch to reinforce the Class II mechanics. It may be directed against the lower molar teeth by means of a bow and Fischer attachment to the archwire in the molar area or through the use of additional round tubes on the upper molars. The headgear can be used as an added anchorage factor in space closure when moving canines. The use of occipital force by itself in selected cases can eliminate the complicated mechanics of anchorage preparation. The disadvantage of this is that it may take longer; its effect varies considerably in different patients and is especially difficult in those cases where cooperation is a problem. With older patients intermittent wearing in the adult dentition may be too slow and not sufficiently effective to accomplish a satisfactory end result.

The use of anchorage units outside the mouth certainly has an advantage in some hands over a poorly manipulated and improperly prepared anchorage arch. However, in using this technique one must recognize the limitations imposed by such technique.

There are many problems created through improper use or attention to anchorage control. Many of us have experienced excessive tipping of buccal segments and undesirable labial inclination of mandibular incisors when injudicious application of elastic force was applied. Lack of attention to the rotations during treatment creates the problem of correction at the end of treatment. Care must be taken to avoid such conditions, for they become a tax on the anchorage units. For instance, correction of a rotated anterior tooth with a removable lever is usually quite simple. However, a highly resistant rotation or several highly resistant rotations may tend to exert an undesirable effect on the anchor arch, especially when the arch is also being used for the correction of Class II or Class III problems. In extraction cases there is the problem of root paralleling. If it is avoided through proper archwire manipulation or the use of inclined brackets as advocated by many men, correction of this tipping problem will eliminate a taxation on our anchor areas and substantially reduce treat-

ment time. Many a well-treated case has been ruined by loss of anchorage in the correction of minor irregularities. Proper appliance manipulation could have avoided these troubles in the first place. Whenever the mechanics are such that undesirable anchorage responses are created, then we must reinforce anchorage or change our mechanics in such a manner as to prevent or eliminate the unwanted tooth movements. The reduction of natural anchorage values in the opposing arch is also important.

To conclude this paper we will summarize briefly what we consider the so-called modern concept of anchorage. It involves the use of existing anchorage, prepared anchorage, and reinforced anchorage. Proper diagnosis through recognition of anchorage availability must be made. In Class II cases we must accept the fact there will probably be migration of the buccal segments. This may be desirable at certain times. If the mechanics are such that there is maximum response and the case ends with a stable denture with desirable improvement in facial form, then we have properly applied the modern concept of anchorage. The timing of force application within favorable growth periods is undoubtedly a major factor in the success of a given technique. If a discrepancy in denture bases exists, then it is believed that a properly prepared mandibular arch will do more to reduce the intermaxillary discrepancy with a corresponding improvement in soft tissue profile in more cases than by other more conventional methods of treatment. This necessarily implies that treatment be instituted during a period of active growth. Dr. Angle's contention that the reciprocal effect of intermaxillary force had considerable benefits in both arches seems even more valid today. Through the years certain undesirable effects of intermaxillary elastics have shown up. The use of anchorage preparation tends to minimize these effects and increase the treatment potential of many cases. Recognition must be made, however, of exceptions in very severe growth patterns. Little benefit will result if anchorage is prepared in cases represented by exceptionally steep mandibular planes coupled with the exceptionally large A-N-B angular relationships. Compromises in treatment must be made in such cases. During treatment if it is found that the existing anchorage is not sufficient, occipital or cervical forces can reinforce this anchorage. Such procedure may be used in non-extraction Class II cases or in Class II, Division 2 arch length cases where additional arch or loss of arch length will upset treatment. Reinforcement of the existing anchorage with intermaxillary elastics to prevent the buccal segments from being carried forward when using vertical loop sections to retract the canines or the maxillary incisors is possible. There are other devices that may be used to reinforce existing anchorage. The soldered lingual arch and the removable lingual arch or palatal plate with finger springs are helpful in space closures.

Extraoral anchorage may by itself be used as the motivating force in the correction of selected cases. If used wisely with proper cooperation in many cases, much satisfaction is derived in reducing the severity of the malocclusion. However, one must recognize that without the complete edgewise appliance in many cases, it is found that to gain one end, very often some sacrifice of our ideals of detailed, finished treatment is required.

Finally, in consideration of the entire problem of present day concepts of anchorage, the selection of the method of anchorage control in the future will depend upon information derived from

the study of treated cases with selected types of mechanics and a comparison of the end results in terms of facial balance, stability, and ease of manipulation.

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Edmund H. Wuerpel

No orthodontist would question the propriety of publishing the obituary of an artist in an orthodontic journal and this is particularly true of the man who exercised such a profound influence on the first great teacher of orthodontia, Edward H. Angle. Although the name, Wuerpel, is largely unknown to men of the past decade or two, there are many orthodontists living who will recall him vividly and affectionately.

The quiet and gentle mien of Edmund Wuerpel gave no hint of the turbulent and adventurous life of his early years. Born in St. Louis in comfortable circumstances, he was transported as a young boy to Mexico with his family. Travelling by covered wagon he was accustomed to frontier hardships even before they had established a home there. Never robust and with eyes that plagued him throughout life he took on the work of a man with the mining companies and the new railroads that were being built. His mother laid out an educational program for him and saw that it was followed in spite of the absence of schools. Besides English she taught him German and he learned Spanish from his contacts with those around him. He later learned French and talked fluently in all of these languages.

About 1879 Edmund's family sent him back to relatives in St. Louis for his further education and by 1885 he was graduated from the Manual Training School with the Selew Medal for the highest four-year record, in spite of the fact that he was unable to use his eyes for the last year. He immediately entered the School of Engineering of Washington University, but a severe illness interrupted his course during the second year and he made a trip to Australia to recuperate. Returning to St. Louis in 1887 he entered the School of Fine Arts. In 1889 he was offered the opportunity of going to France to study and he seized it.

Wuerpel lived in Paris for six years, studying at the Julian Academy and the Ecole des Beaux Arts, but his interests were wider than those of the average art student. He was always interested in the problems of other people and this interest led to an ever widening circle of acquaintances. Among others whom he could claim as friends were James Whistler, Sarah Bernhardt, Whitelaw Reid, and Rodman Wanamaker.

Upon his return to St. Louis in 1894 he was immediately put in charge of the Life Class at the Art School of Washington University and advanced over the years to become Dean of the Art School. Before his retirement he was awarded the honorary degree of Doctor of Fine Arts in 1947 and cited for the longest term, 53 years, ever served by a member of the staff of the University.

When Angle was conducting his earliest courses around the turn of the century in St. Louis, he was trying to formulate his ideas of beauty of the human race. He knew Wuerpel only by reputation but he sought his help. As Wuerpel subsequently recounted that first meeting, it went somewhat as follows:

Angle introduced himself as an orthodontist and in those days that term had to be defined. He explained that the regulation of the teeth had far-reaching effects on the face and he wished to give his students some rule to guide them in their practices. He produced a lantern slide of the Apollo Belvedere and asked Wuerpel if that would not be a good model toward which they might work.

Wuerpel had listened patiently to

the recital thus far, but at this point he protested vehemently. "Do you want to make all faces alike and do you want them all to be Greeks?" he roared. "What a hideous idea!" Then he started to explain that beauty was not of a single type; that it was dependent on the observer and he in turn was influenced by race, color, culture and background. When he finally finished his harangue, Angle was perspiring copiously, but he was enthralled. His only response was, "Will you come and tell my students what you have told me?"

Thus began a friendship that ended only with Angle's death in 1930. Wuerpel lectured to every class of the Angle School in St. Louis, New York, and New London, Connecticut, and to many of those trained later at Pasadena. With the opening of the Graduate Course at Illinois, Wuerpel continued his lectures there until it became too difficult to make the trip to Chicago. As an honorary member of the Angle Society he and Mrs. Wuerpel attended all of its meetings until recent years and at the last meeting of the American Association of Orthodontists held in St. Louis they received many old acquaintances.

No one who ever heard Wuerpel lecture on Art ever forgot it. He introduced his listeners to a "school" by describing the environment and the times in order to explain why they painted as they did. Then he pointed out the details that characterized them and wherein they differed from other schools. His knowledge of the history of art ranged over the entire field. Nor did he neglect the field of ethics. Some of his talks were, in reality, sermons. One of these "Ideals and Idealism" given before the Angle Society was specially printed and sent to all of its members.

Wuerpel and Angle were as unlike as two men could be and their strong friendship was a striking example of the attraction of opposites. The aggressive, sometimes intolerant Angle was a marked contrast to the gentle, soft spoken Wuerpel. Yet they had much in common in their sense of humor, their love of nature, and of all things beautiful including those man made. They loved nothing more than to share with each other anecdotes, antiques, and even vacations. They could talk together for hours and under almost any circumstances and it was no doubt during such intercourses that Wuerpel's influence on Angle's thinking was exercised. Together they designed and planned the Angle-Wuerpel orthodontic table which marked the first step in the transformation of the dental office to one that was less fearsome and more fitting for young patients.

Shortly after his return from Paris Wuerpel married Minnie Clay Johnson of St. Louis whom he had known before he went abroad. Three daughters were born of this union and it was with the second of these, Lois Bowles, that the elder Wuerpels were making their home when Edmund died in February, 1958 at the ripe age of almost ninety two years. Mrs. Wuerpel passed away on May 18, 1958, less than three months after Mr. Wuerpel's death.

A. G. B.

ANNOUNCEMENT

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The Angle Orthodontist

A magazine established by the co-workers of Edward H. Angle, in his memory . . .

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The author should submit the original typed copy of the manuscript, double-spaced on bond paper. The author's name and city of residence should appear immediately after the title, and the street address should appear at the end of the article.

Do not use symbols to indicate teeth; in *tables* teeth may be designated as U-1 or L-6, but in the text names of teeth should be fully written out.

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